HAIR: History of Animals using Isotope Records

(You are what you eat . . . plus a few ‰)

- Thure Cerling

University of Utah

Thanks

- Linda Ayliffe, Gabe Bowen, Claire Cerling, Dylan Cerling, Lesley Chesson, Edna Ehleringer, Jim Ehleringer, Iain Douglas-Hamilton, Jackson King'oo, Passey, Dave Podlesak, Chris Remien, Jerry Schuster, Matt Sponheimer, Kevin Uno, George Wittemyer

- *IsoForensics, Kenya Wildlife Service, National Science Foundation, Packard Foundation, Save-The-Elephants, Sheldrick Wildlife Trust*

PNAS 10 Nov 2009

Cooperation and individuality among man-eating lions

Justin D. Yeakel[1,1], Bruce D. Patterson[2], Kena Fox-Dobbs[3], Mercedes M. Okumura[4], Thure E. Cerling[4], Jonathan W. Moore[5], Paul L. Koch[6], and Nathaniel J. Dominy[1,6,7]

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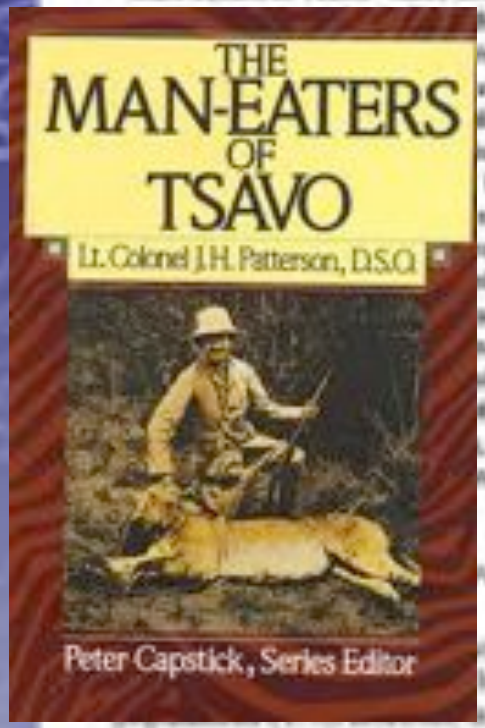
Edited by Kristen Hawkes, University ... ...er 23, 2008 (received for review May 13, 2009)

Cooperation is the cornerstone ... most cats, a coalition of two adu... Kenya, cooperatively killed doze... "man-eaters of Tsavo" have sinc...



...ity of human predation (up to 30% ...its of 1898) is also associated with ..., which may have further promoted ...ual prey under perturbed environ...

...Panthera leo | Tanta | Tsavo

...tions can result from high intraspe... ...has been reported in many animal ...its effects on the social behaviors of ...gregarious species are poorly understood. Among lions, coopera... ...tive behaviors are well known (1–7), yet the presence of ...legends (8), theaters (9), and specialized hunters (7) within

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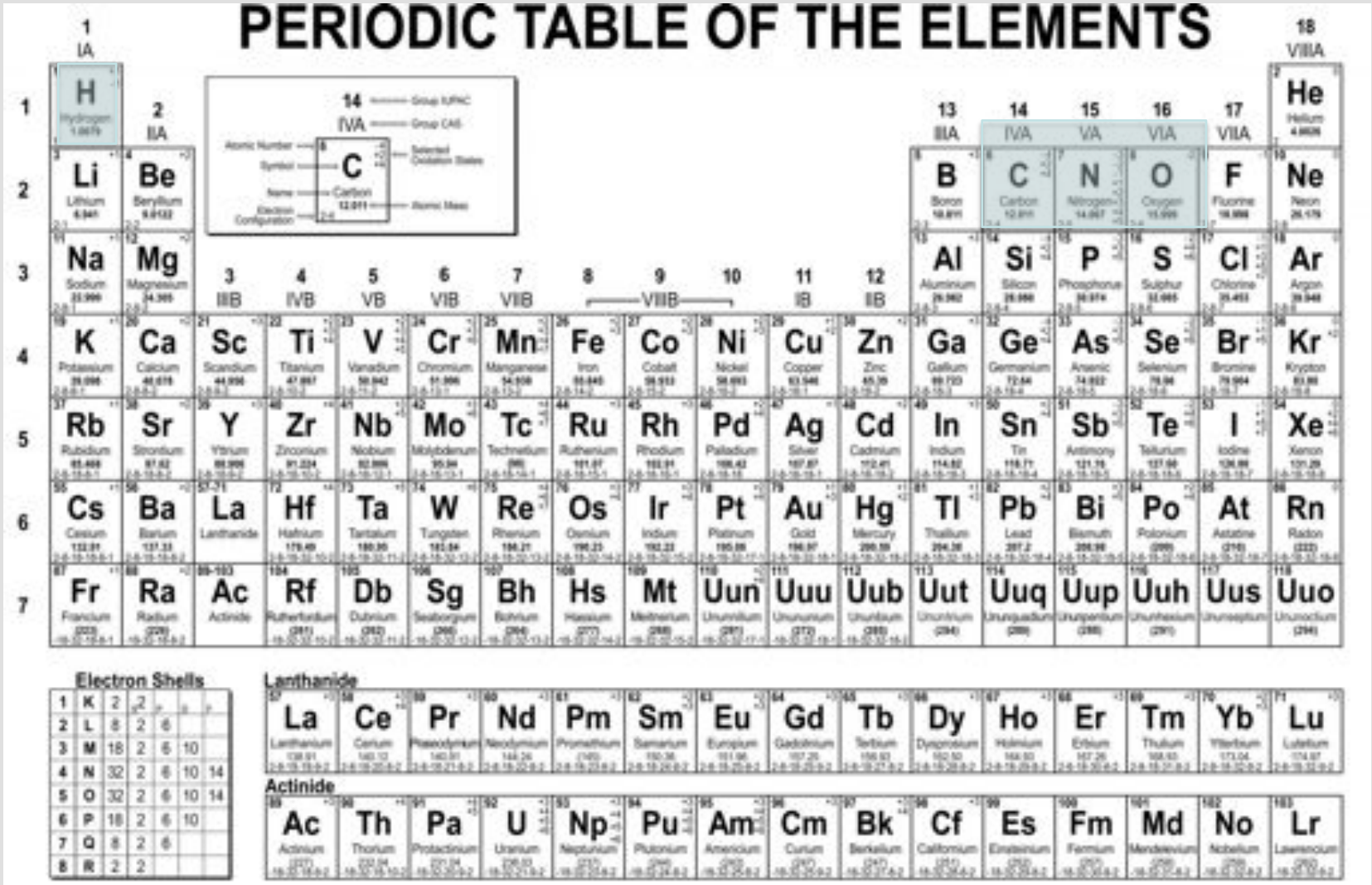
Edited by Kristen Hawkes, University of Utah, Salt Lake City, UT, and approved September 23, 2009 (received for review May 13, 2009)

"I'm trying to eat more vegetarians."

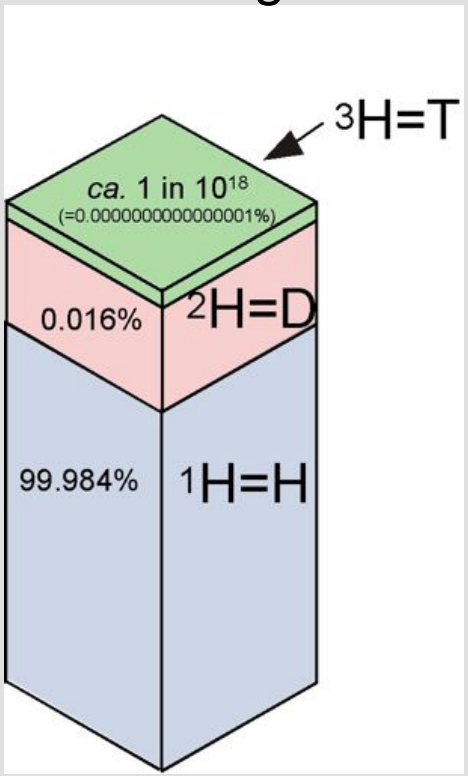
The New Yorker,14 Dec 2009

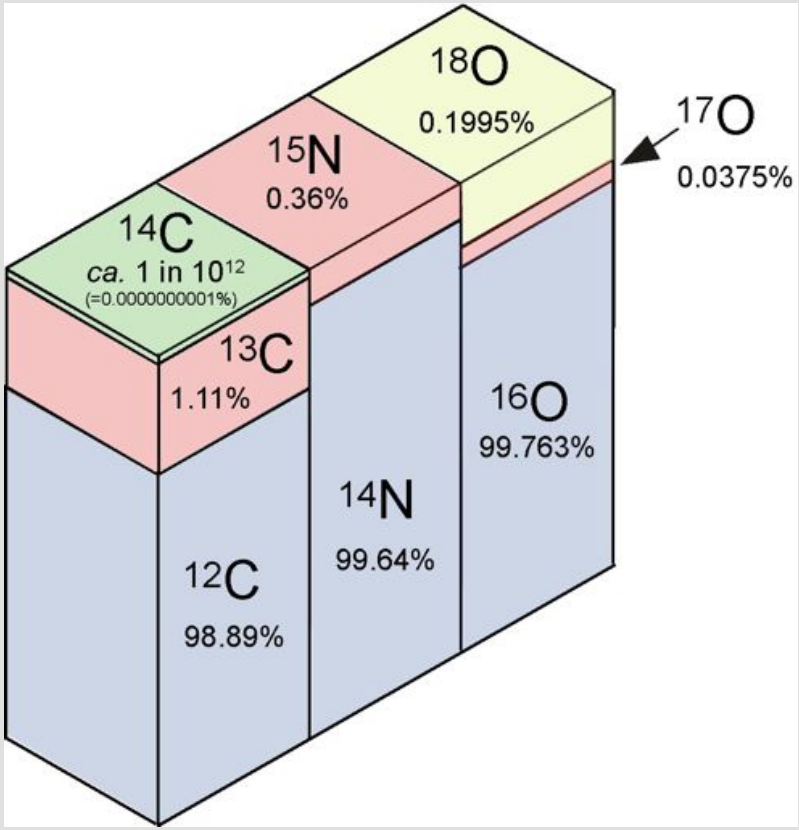
Elements are defined by the number of protons in the nucleus:

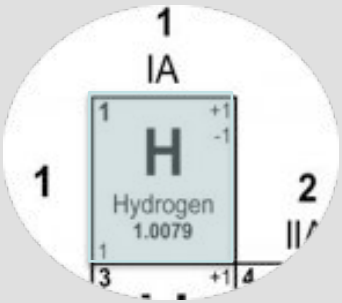
1=H, 2=He, 3 = Li, 4 = Be, 5 = B, 6 = C, 7 = N, 8 = O, and so on . . .

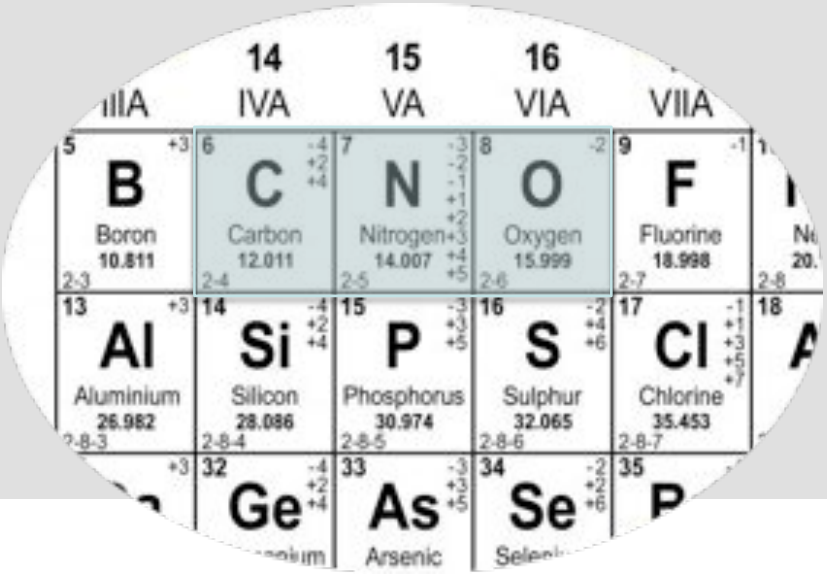


Isotopes are the different numbers of neutrons for a given proton configuration



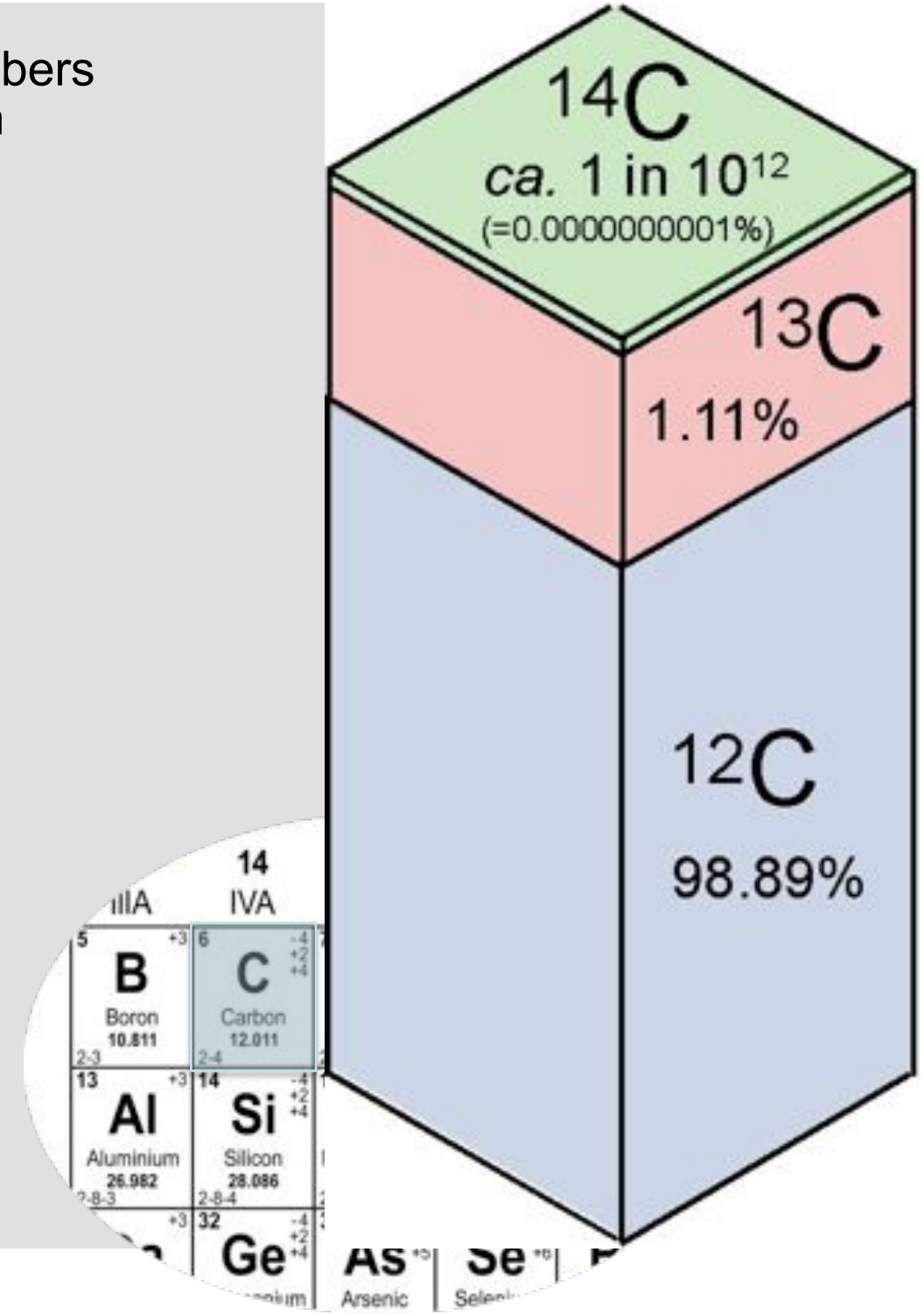






Isotopes are the different numbers of neutrons for a given proton configuration

Isotope	protons	neutrons
^{12}C	6	6
^{13}C	6	7
^{14}C	6	8



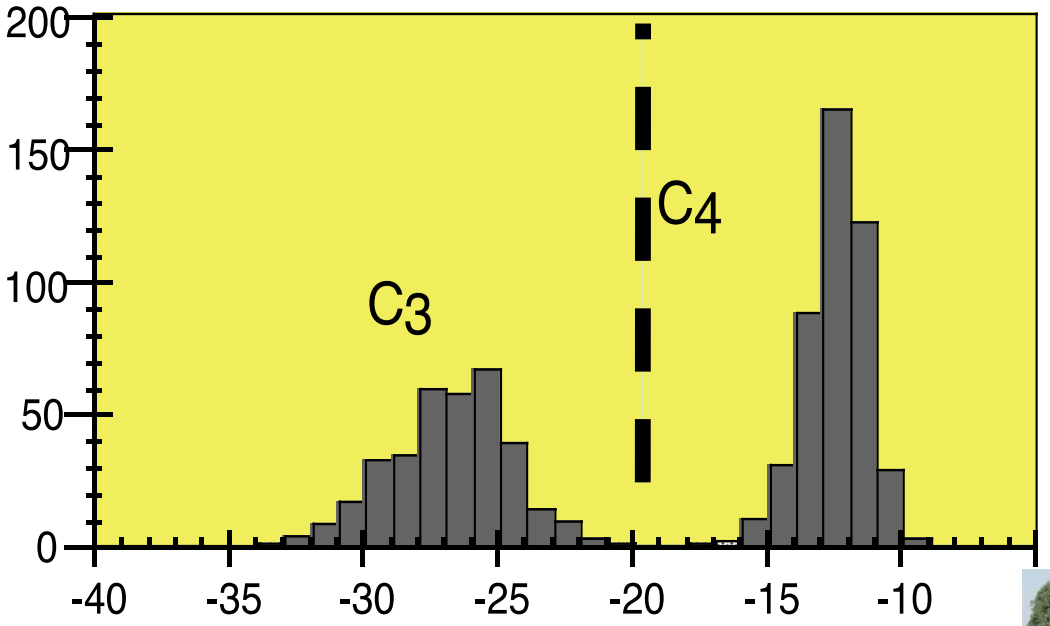
Isotope terminology

- $R_{phase} = {}^{13}C/{}^{12}C$ ratio in "phase"
- $\delta^{13}C$ (‰) = $(R_{phase} / R_{standard} - 1)*1000$
- On Earth, ^{13}C ranges from 1.04% to about 1.14% (*ca.* $\delta^{13}C$ range from -65‰ to +25‰)

Stable isotopes and animal behavior on different time scales

- A Traveler's Tale
- You are what you eat. Plus a few ‰.
- Reaction progress variable
- Modern elephant isotope ecology
- NCIS - forensics

$\delta^{13}C$ distinction between C_3 and C_4 plants



C_3 and C_4 photosynthesis

- C_3 plants
- most dicots
- cool-season grasses
- Foods: vegetables, fruits, beans, wheat, barley, rye, meat (from diet)

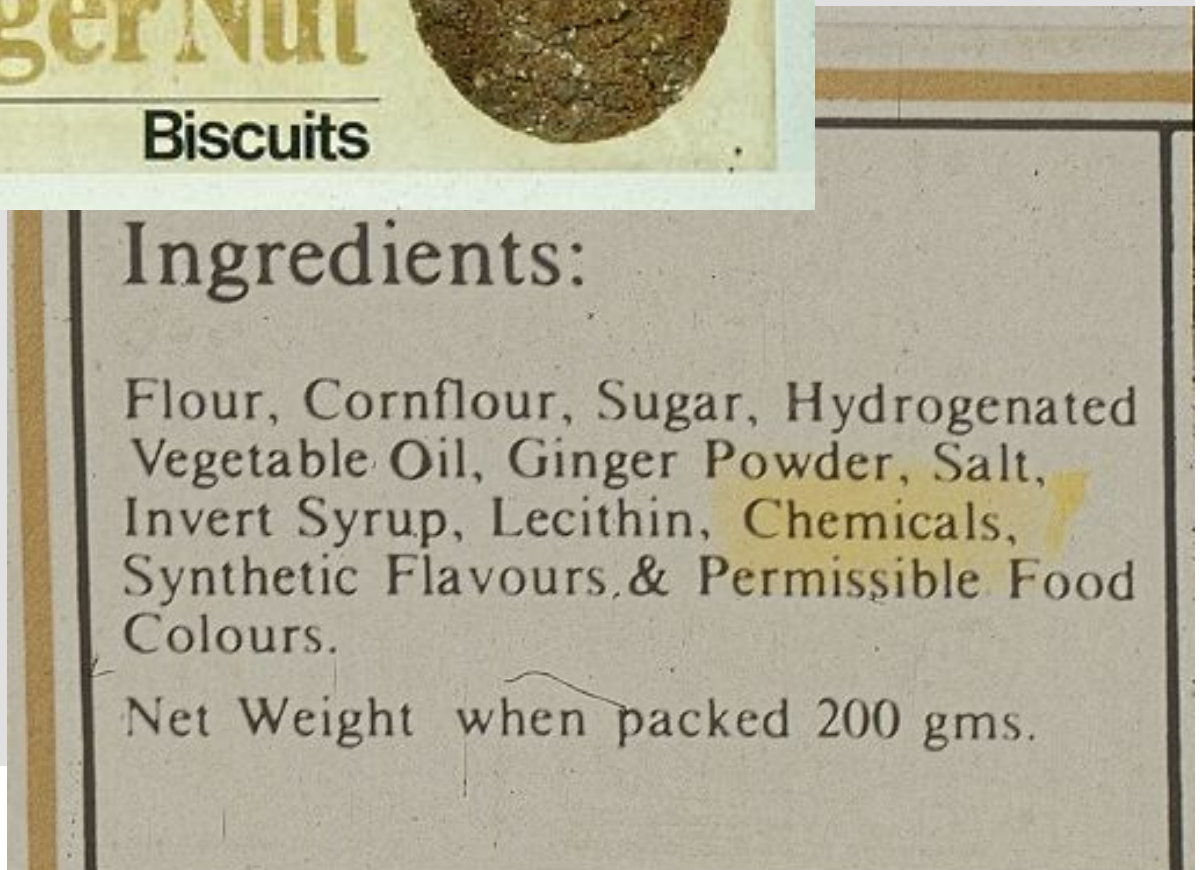
- C_4 plants
- rare in dicots
- tropical grasses and sedges
- Foods: maize, sorghum, sugar cane, millet, tef, fonio, and meat (from diet)

You are what you eat . . .

. . . plus a few permil (‰)

You are . . .

. . . what you eat.

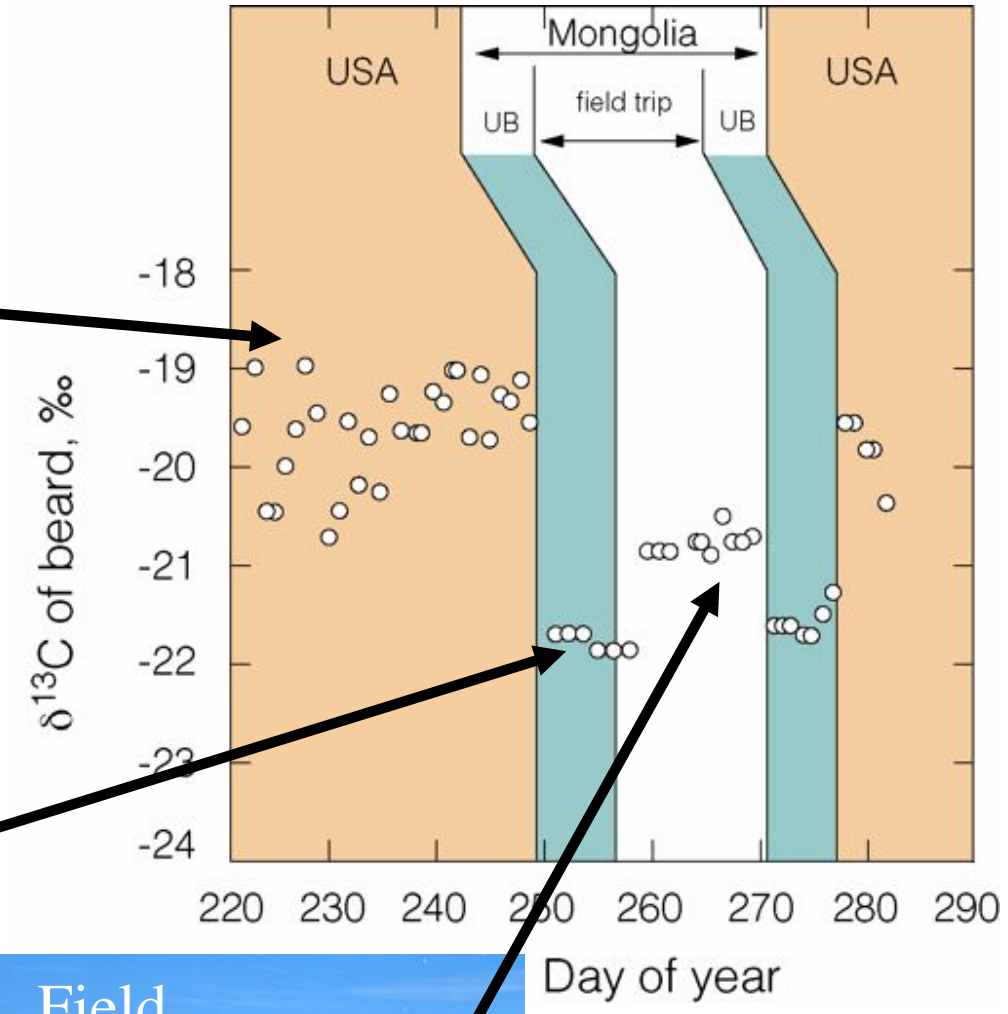


What the traveler ate

What the traveler ate . . .

Got milk?

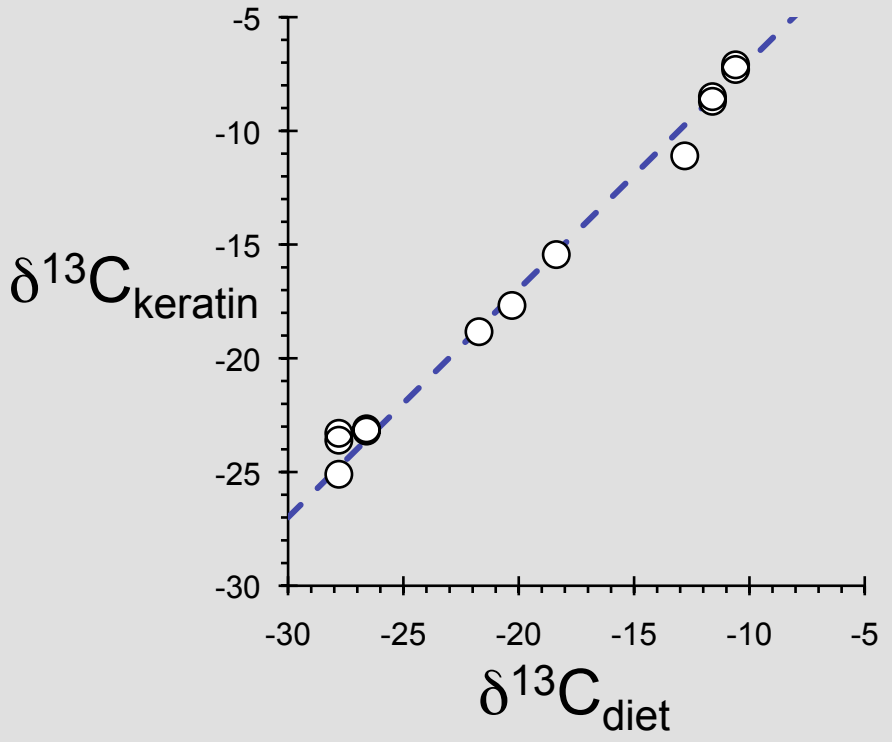
Movements between Mongolia and USA are recorded in beard hair



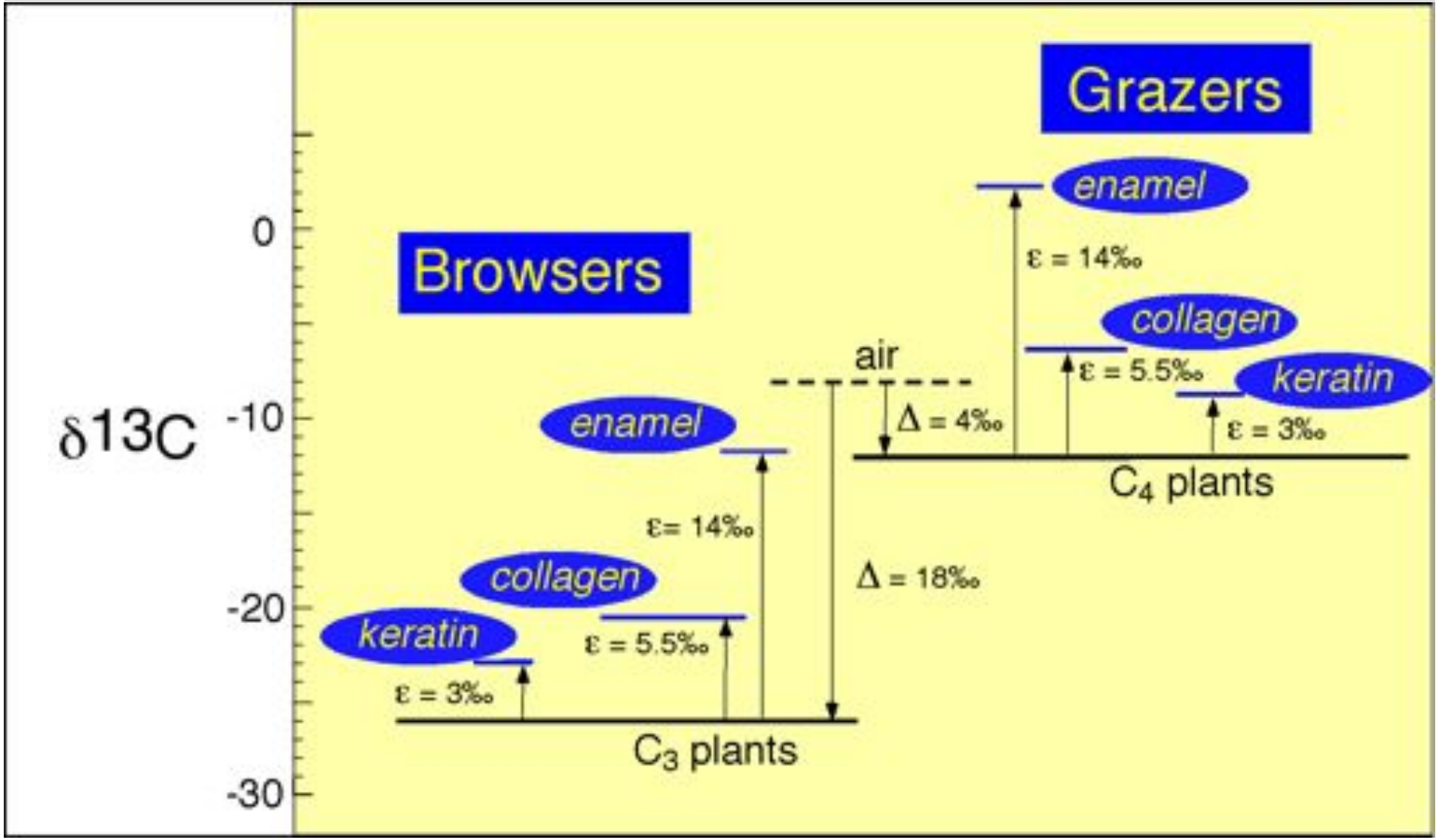
Univ Utah-BYU : controlled diets


P19

Isotope enrichment $\varepsilon^*_{hair\text{-}diet}$ =3.1‰



Isotope discrimination (air to plant) and enrichment (diet to animal tissue)



Controlled diet change
UU – BYU

diet change of horses: C_3 to C_4. Back to C_3 after 150 days. Ends with 7 day spike of C_4

- horse tail hair sectioned to 1 mm (ca. 1 day)

Team Utah-BYU

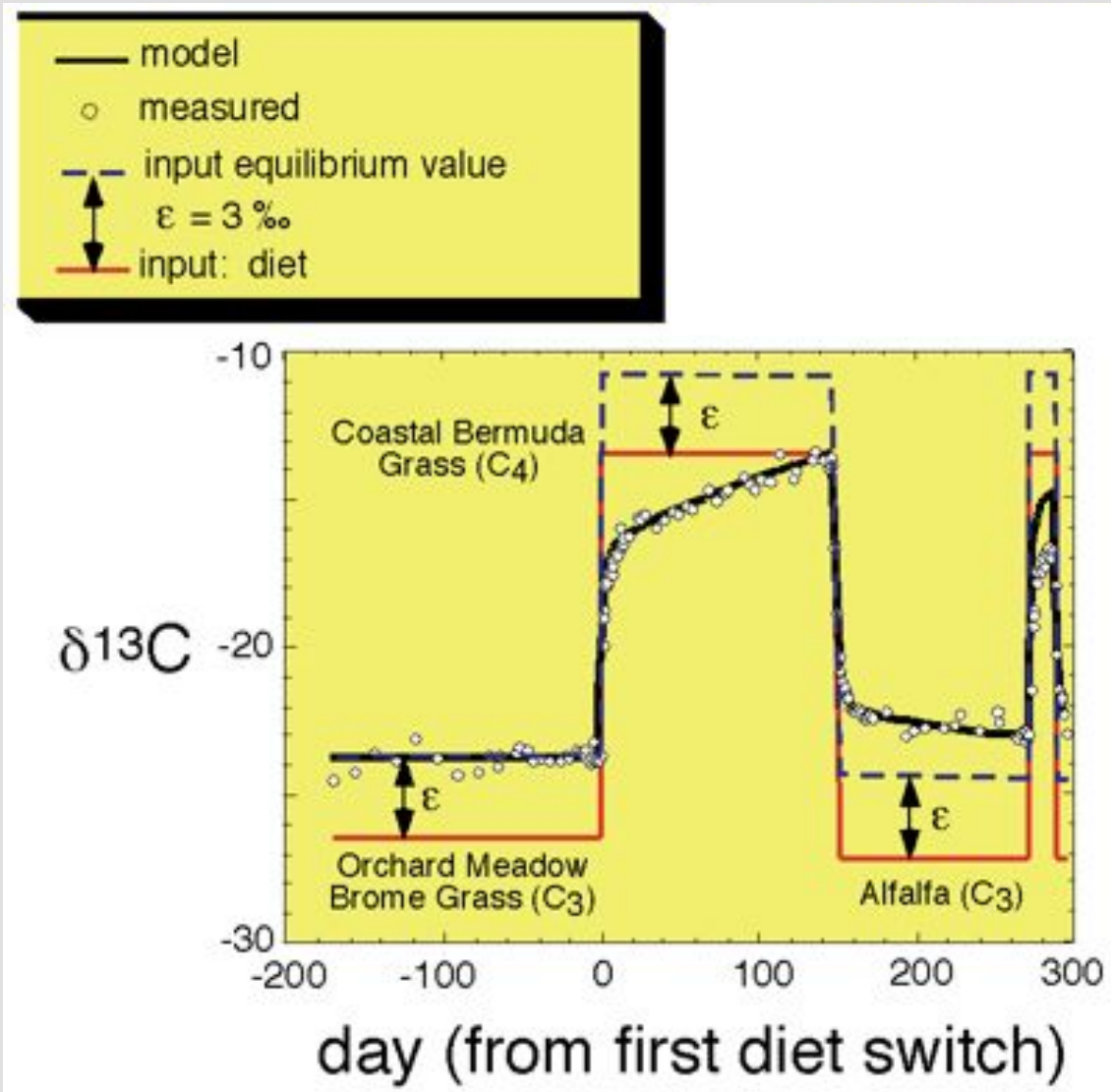
Dandy with Linda Ayliffe

Controlled diet change
UU - BYU

- diet change: C_3 to C_4. Back to C_3 after 150 days. Ends with 7 day spike of C_4
- horse tail hair sectioned to 1 mm (ca. 1 day)

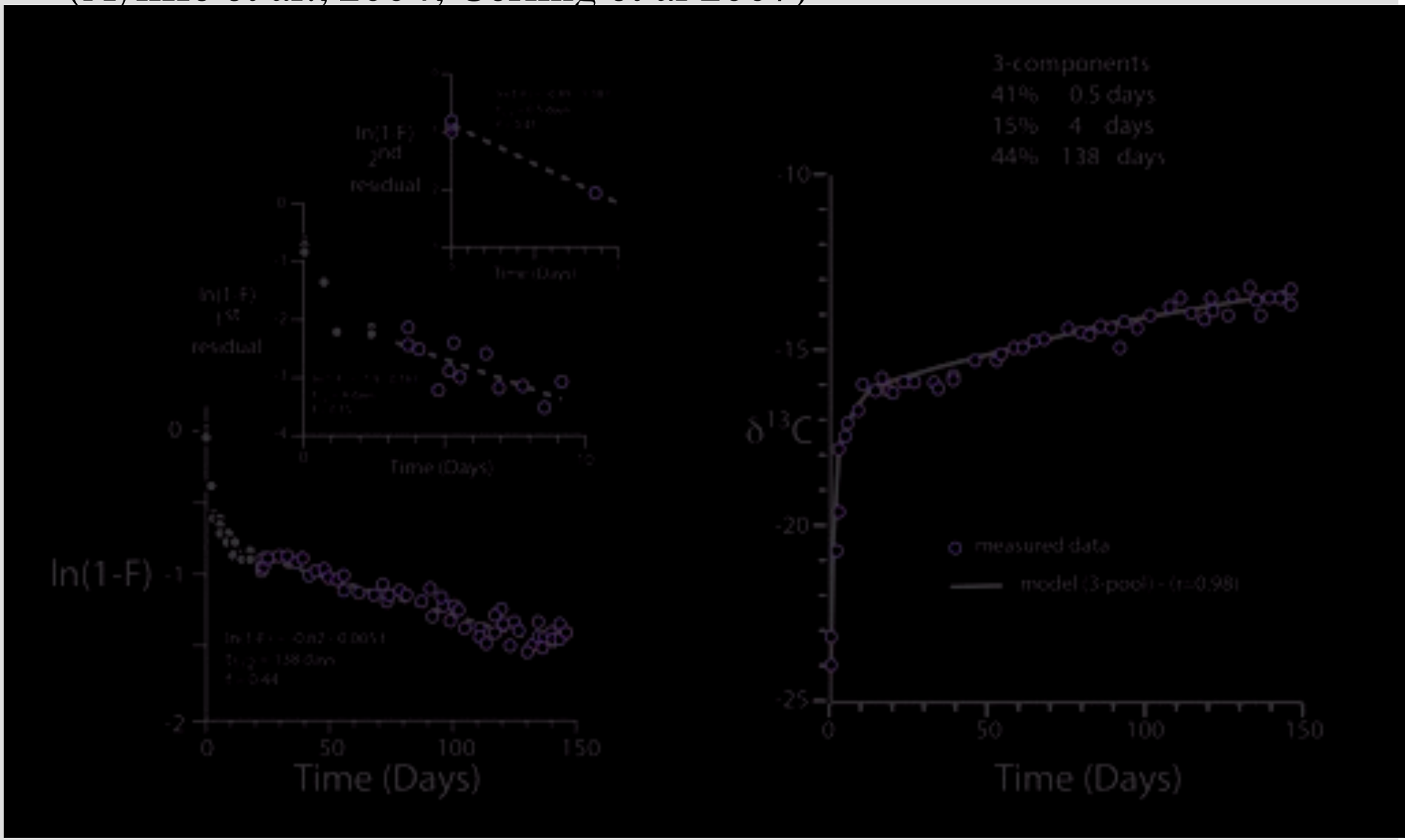
Hair treated as $dN_i/dt = -\lambda_i N_i$

Isotope composition of hair predicted from known



-Ayliffe et al. 2004

Treat as “reaction progress”: isotope values normalized from 0 to 1 (Ayliffe et al., 2004; Cerling et al 2007)



Model to directly calculate diet from isotope measurements of hair

Each pool changes as:

$$\delta_{i,(t)} = \delta_{i,(t\text{-}1)}\, e^{-\lambda_i(\Delta t)} + \delta_{D(t)}\left(1 - e^{-\lambda_i(\Delta t)}\right)$$

And thus diet is directly calculated as:

$$\delta_{D(t)} = \frac{\left(\frac{\delta_H + 1000}{\alpha_{HD}} - 1000\right) - \left(\sum_{i=1}^{n} f_i \delta_{i,t-1} e^{-\lambda_i \Delta t}\right)}{\left(\sum_{i=1}^{n} f_i (1 - e^{-\lambda_i \Delta t})\right)}$$

(Although need to guess values at t = 0)

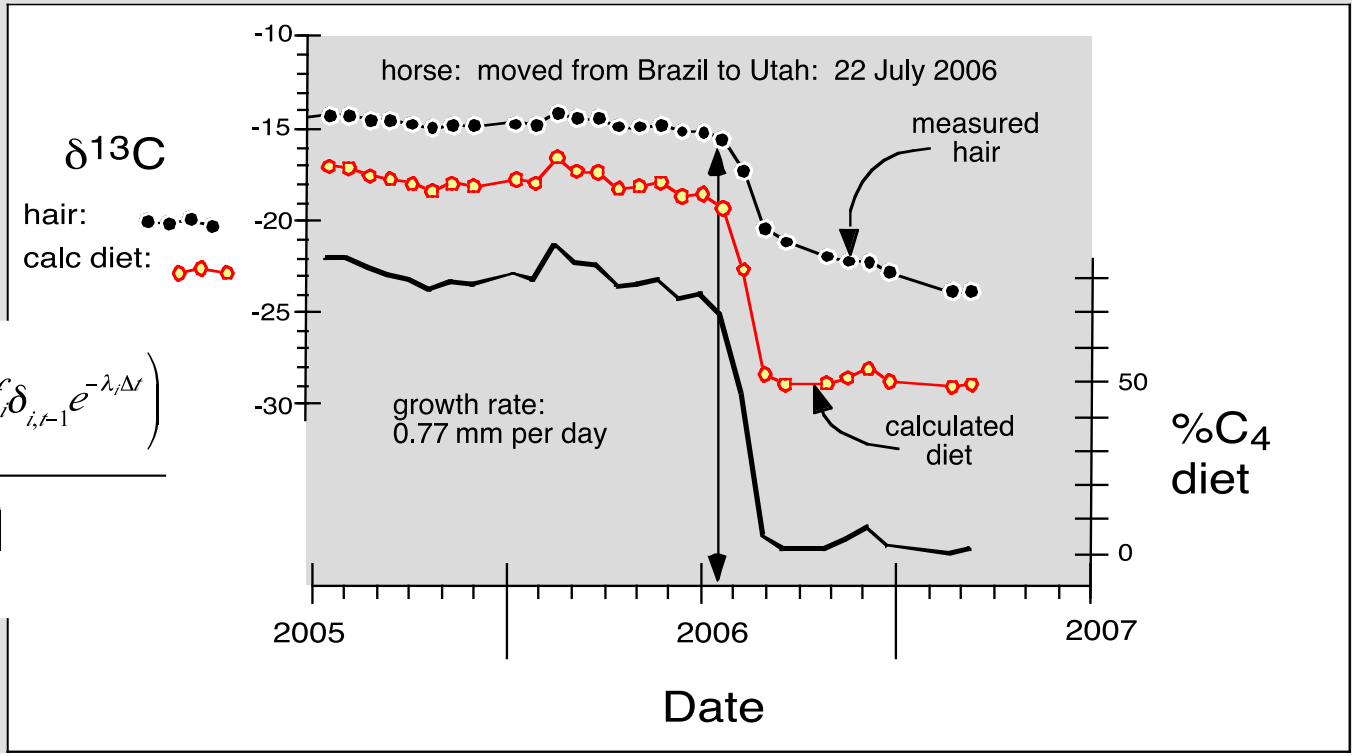
-Cerling et al., 2004

Direct calculation of diet from sequence

- Horse moved from Brazil to Utah: July 2006
- Sampled April 2007
- Assume growth rate of 0.77 mm per day to match known time of movement
- Model of Cerling et al. (2007)

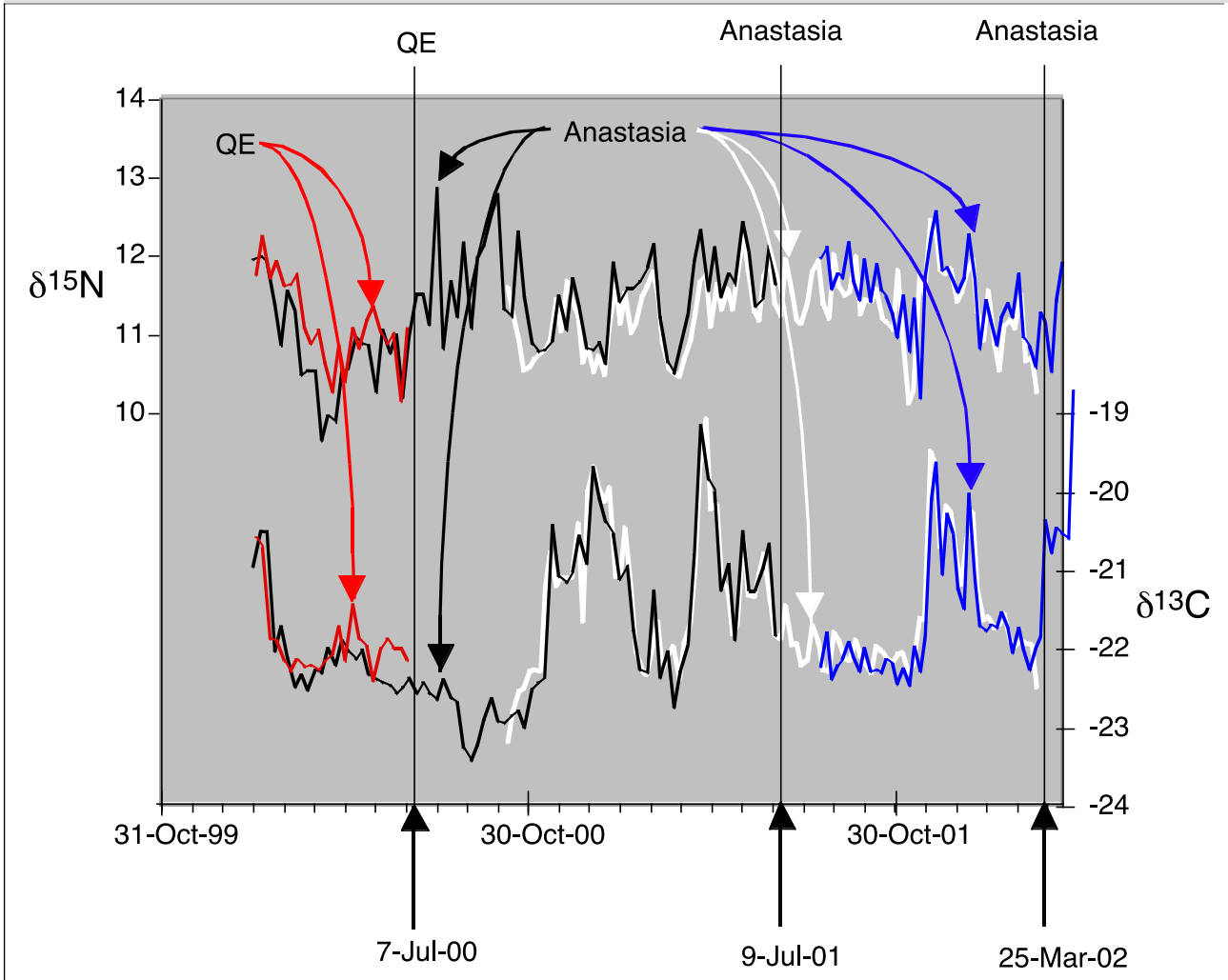
-unpublished

$$\delta_{D(t)} = \frac{\left(\frac{\delta_H + 1000}{\alpha_{HD}} - 1000\right) - \left(\sum_{i=1}^{3} f_i \delta_{i,t-1} e^{-\lambda_i \Delta t}\right)}{\left(\sum_{i=1}^{3} f_i (1 - e^{-\lambda_i \Delta t})\right)}$$



GPS collars and elephant hair

How do we get growth rates of hair?

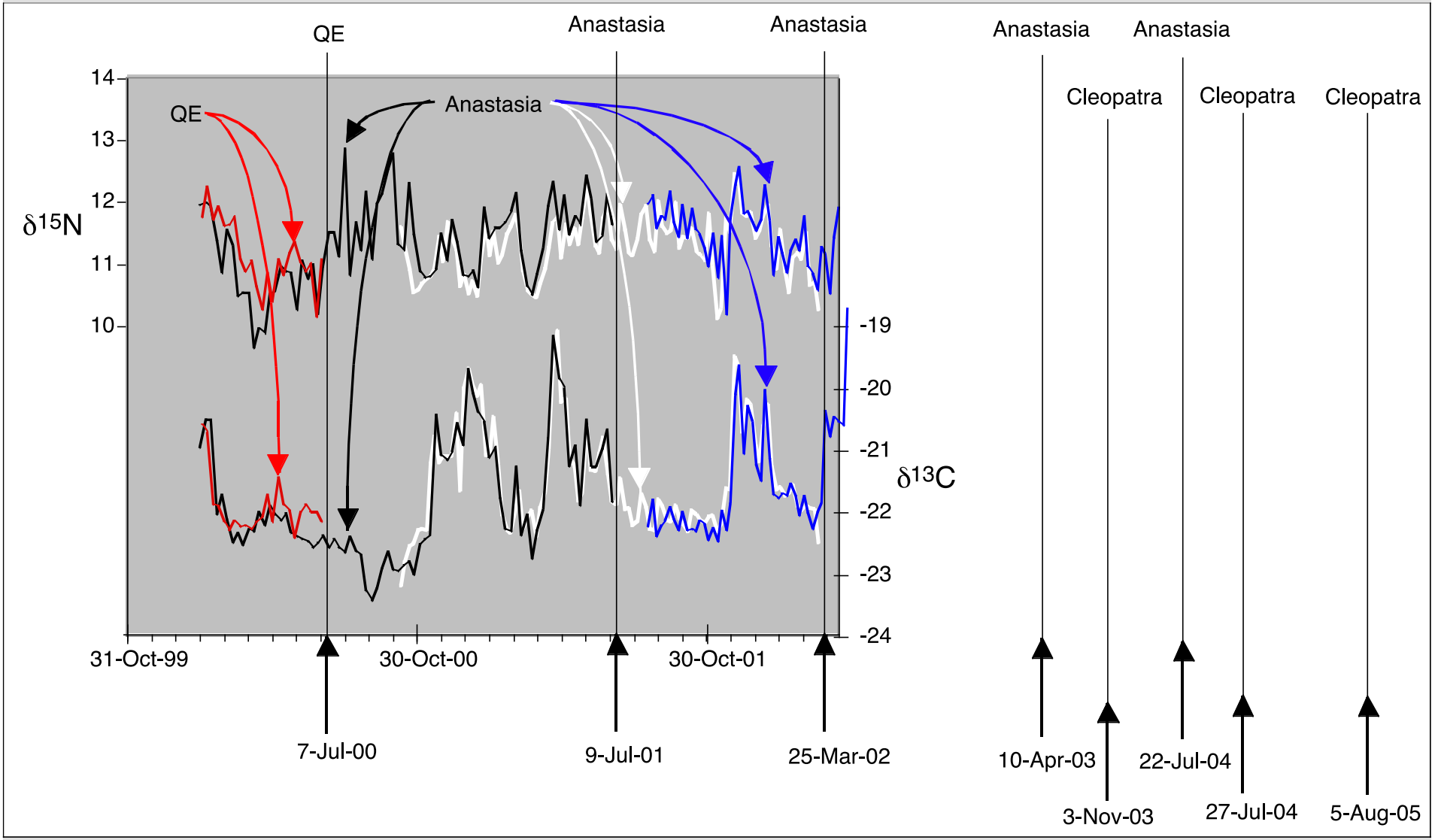


Collect hair from same indviudal several times.

"Wiggle Match"

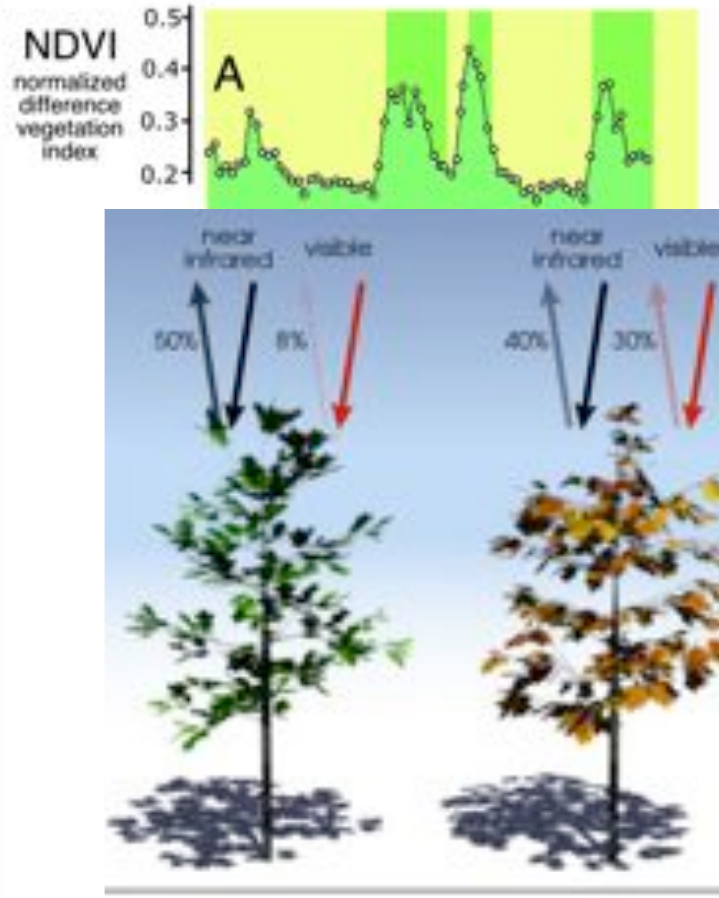
Can also correlate to other individuals QE is in same family unit as Anastasia (QE is mother of Anastasia)

Baton is passed to Cleopatra (sister)



Quantify the importance of grass during rainy season

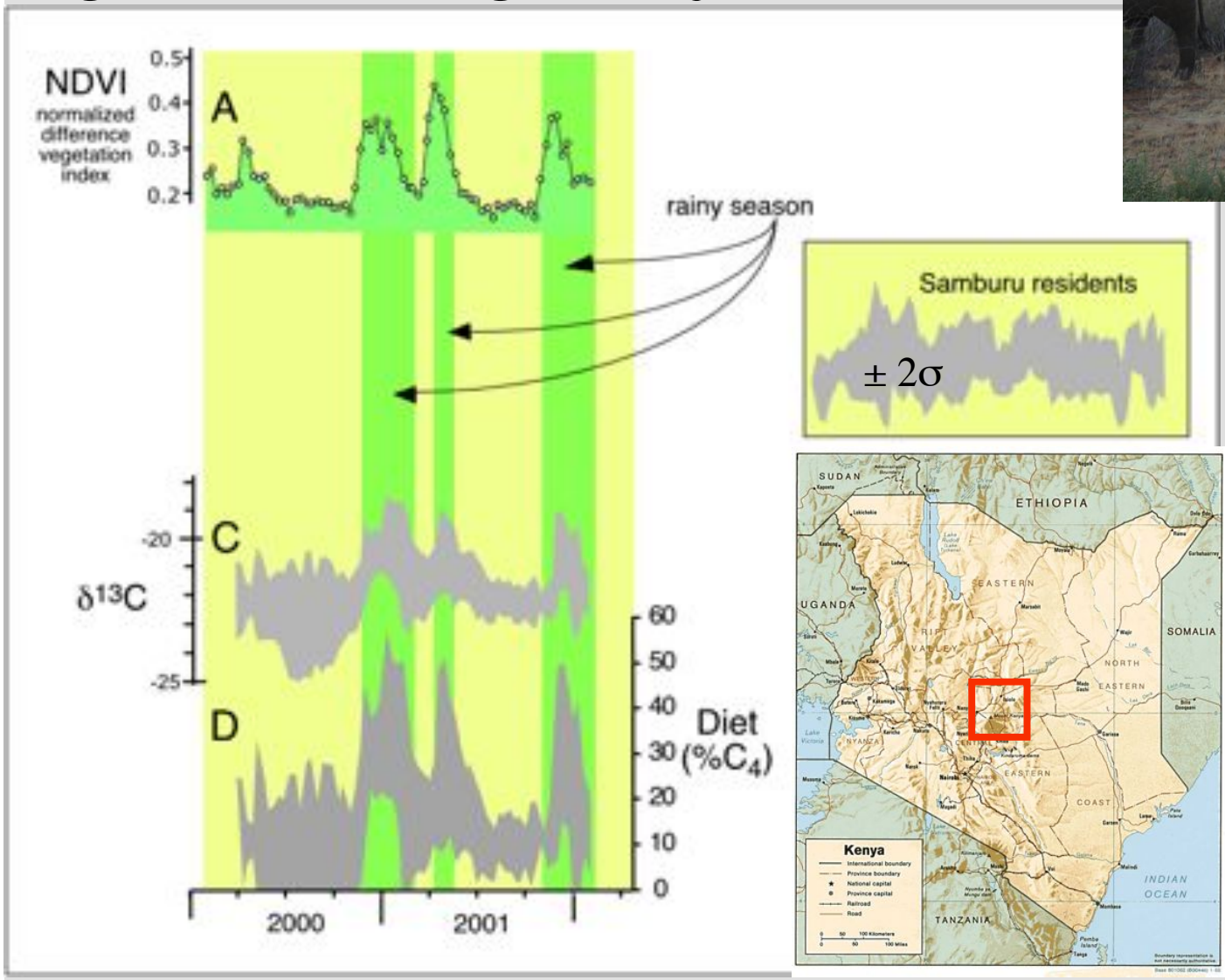
Samburu



$$NDVI = \frac{(NRI-VIS)}{(NRI+VIS)}$$

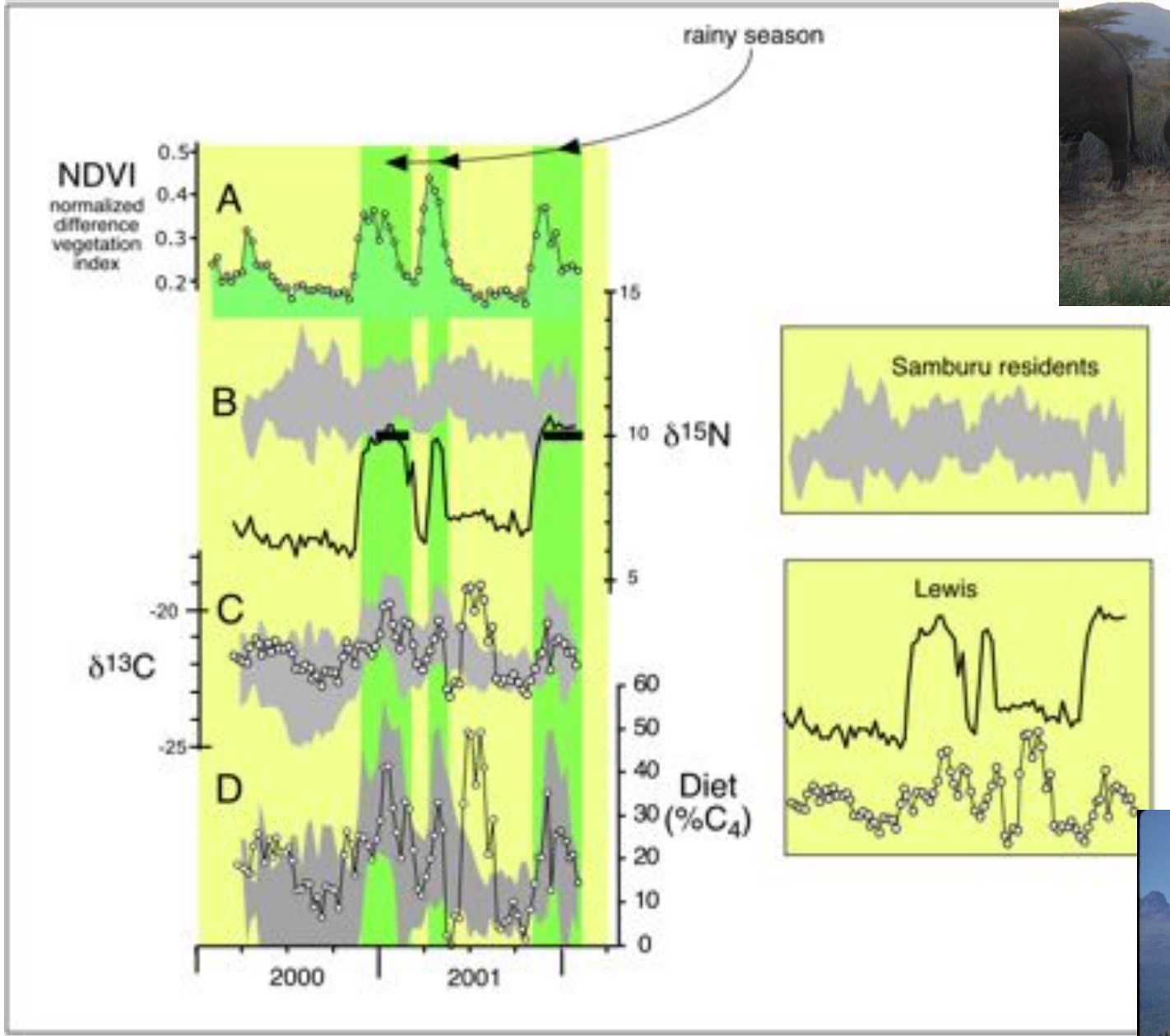
Quantify the importance of grass during rainy season

Samburu



Data is for average ± 2σ for 5 Samburu Reserve resident elephants

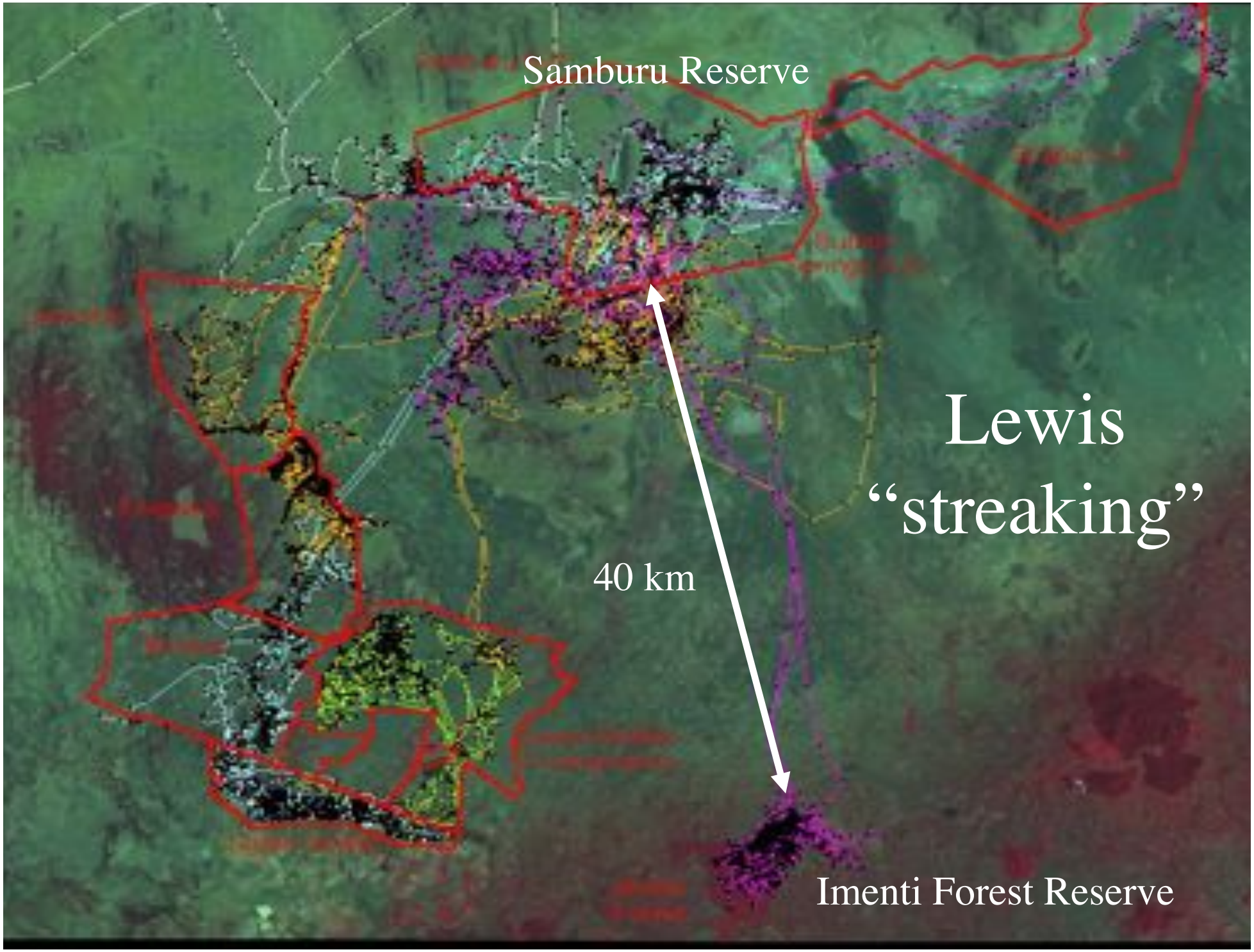
Lewis, the wandering elephant

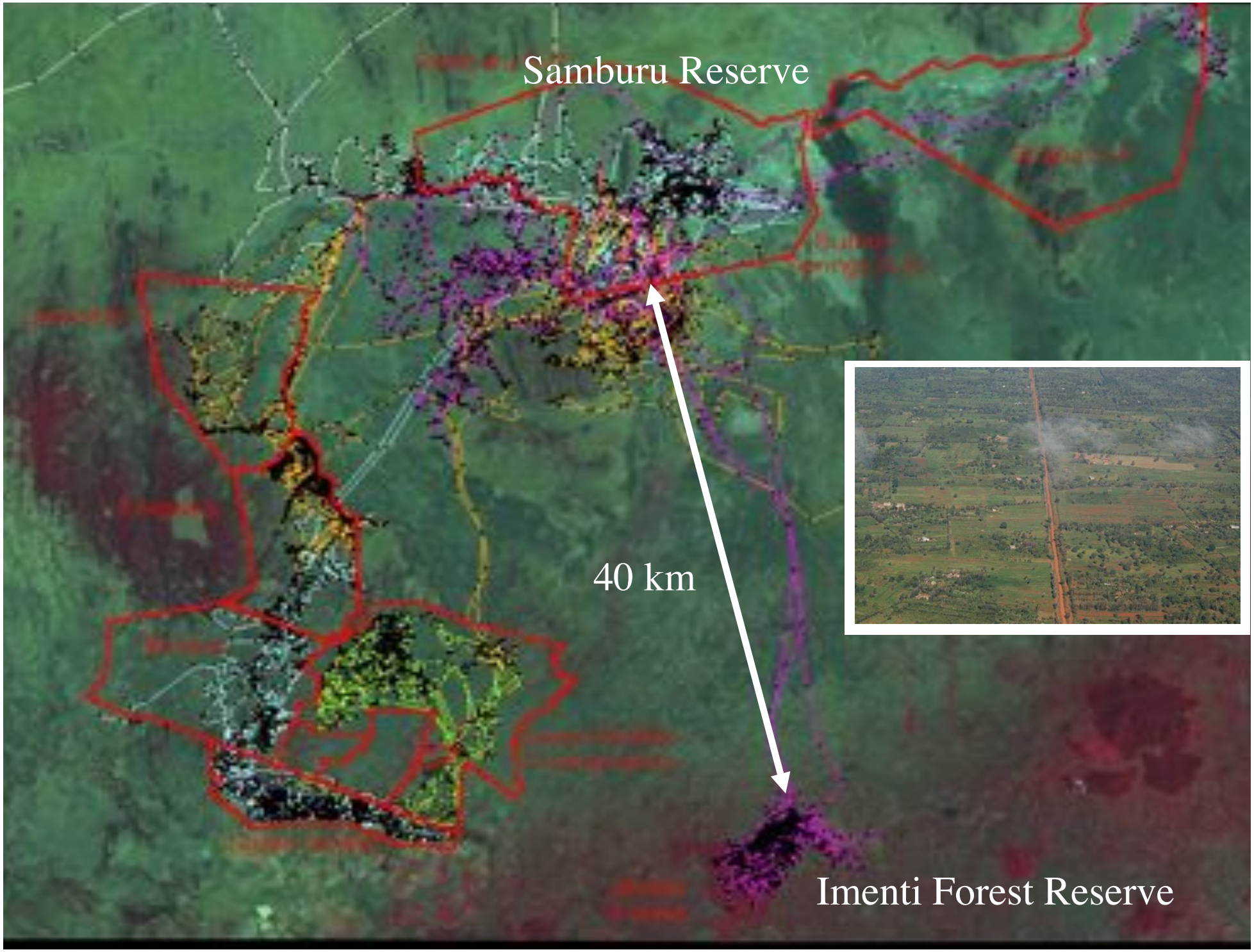


Samburu

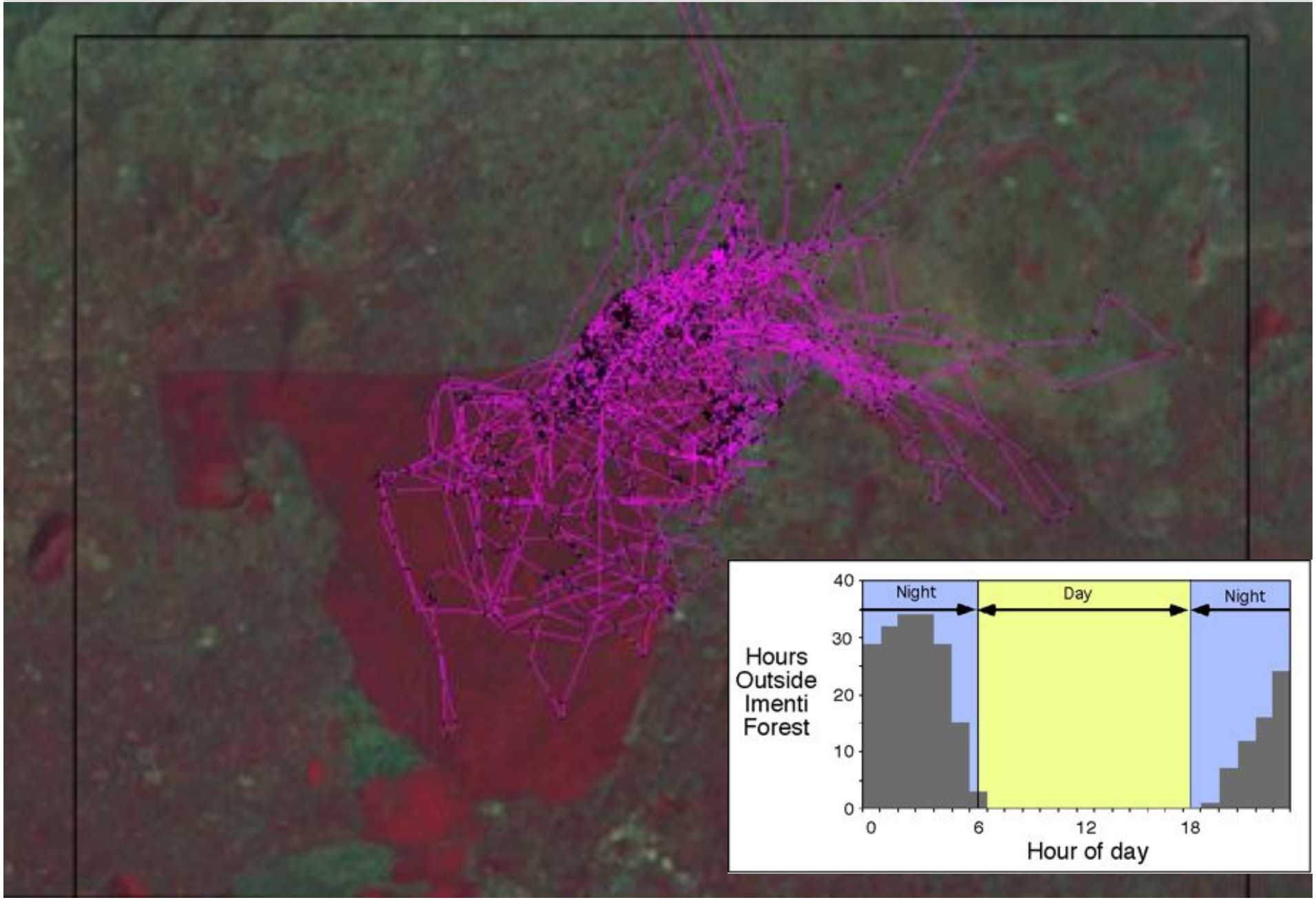
Seasonal migration

Mt. Kenya

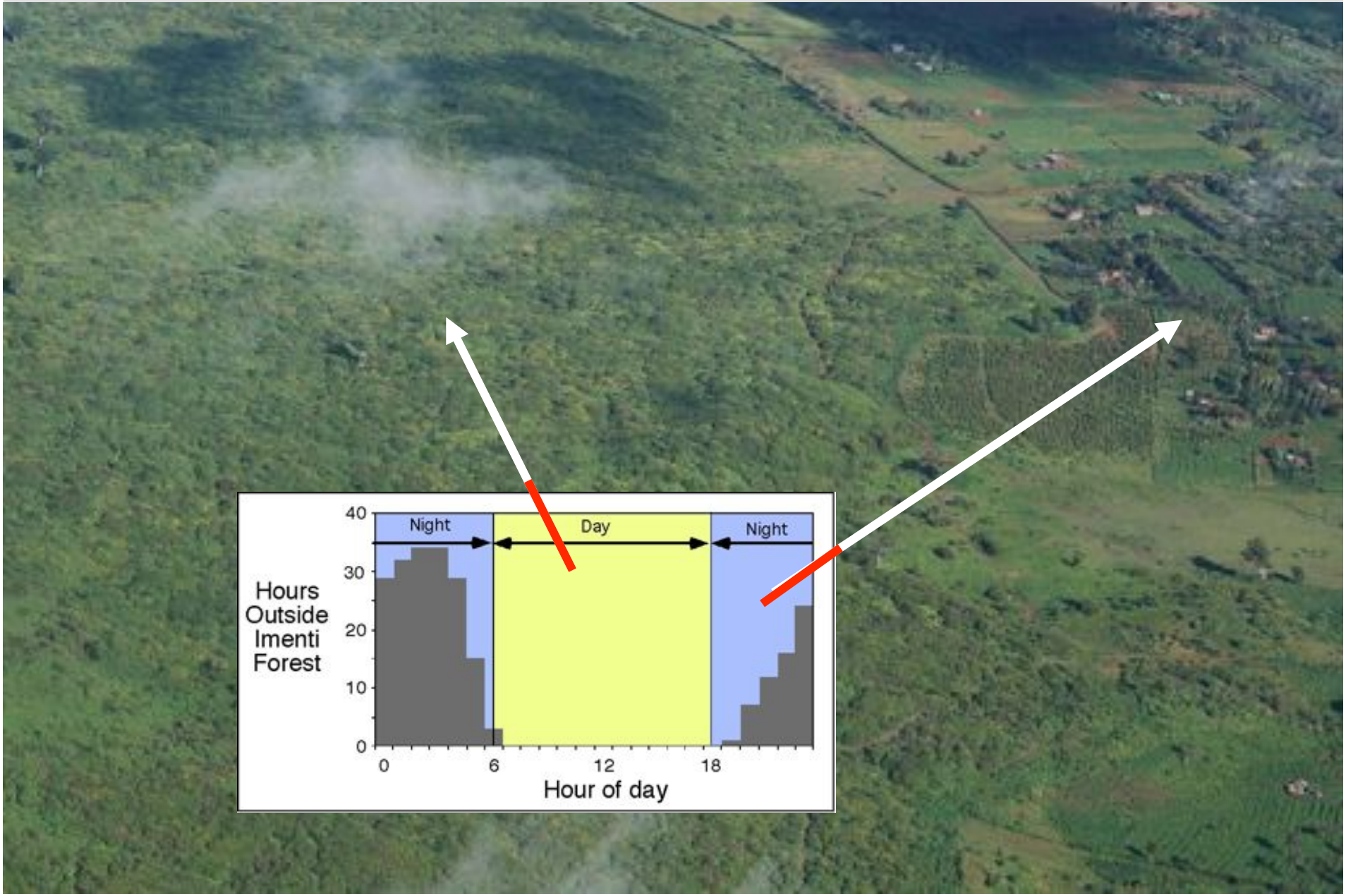

Samburu Reserve
Lewis
"streaking"
40 km
Imenti Forest Reserve


Samburu Reserve
40 km
Imenti Forest Reserve

Crop raiding by Lewis occurs at night: outside the Imenti Forest

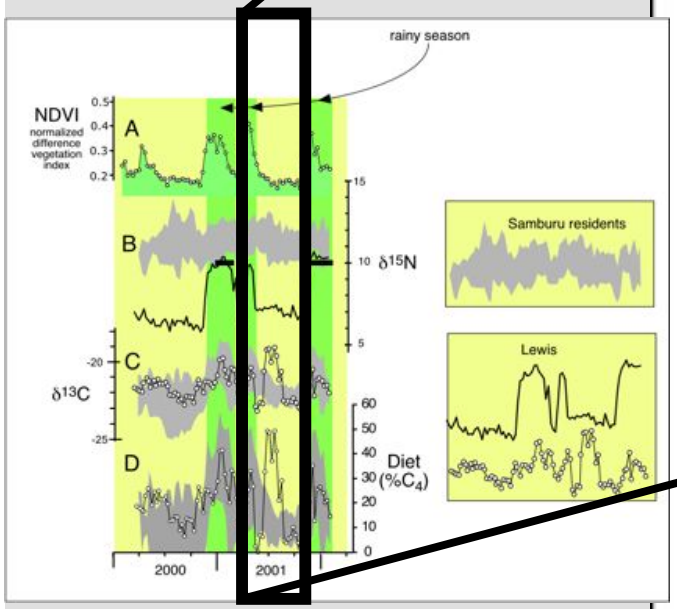


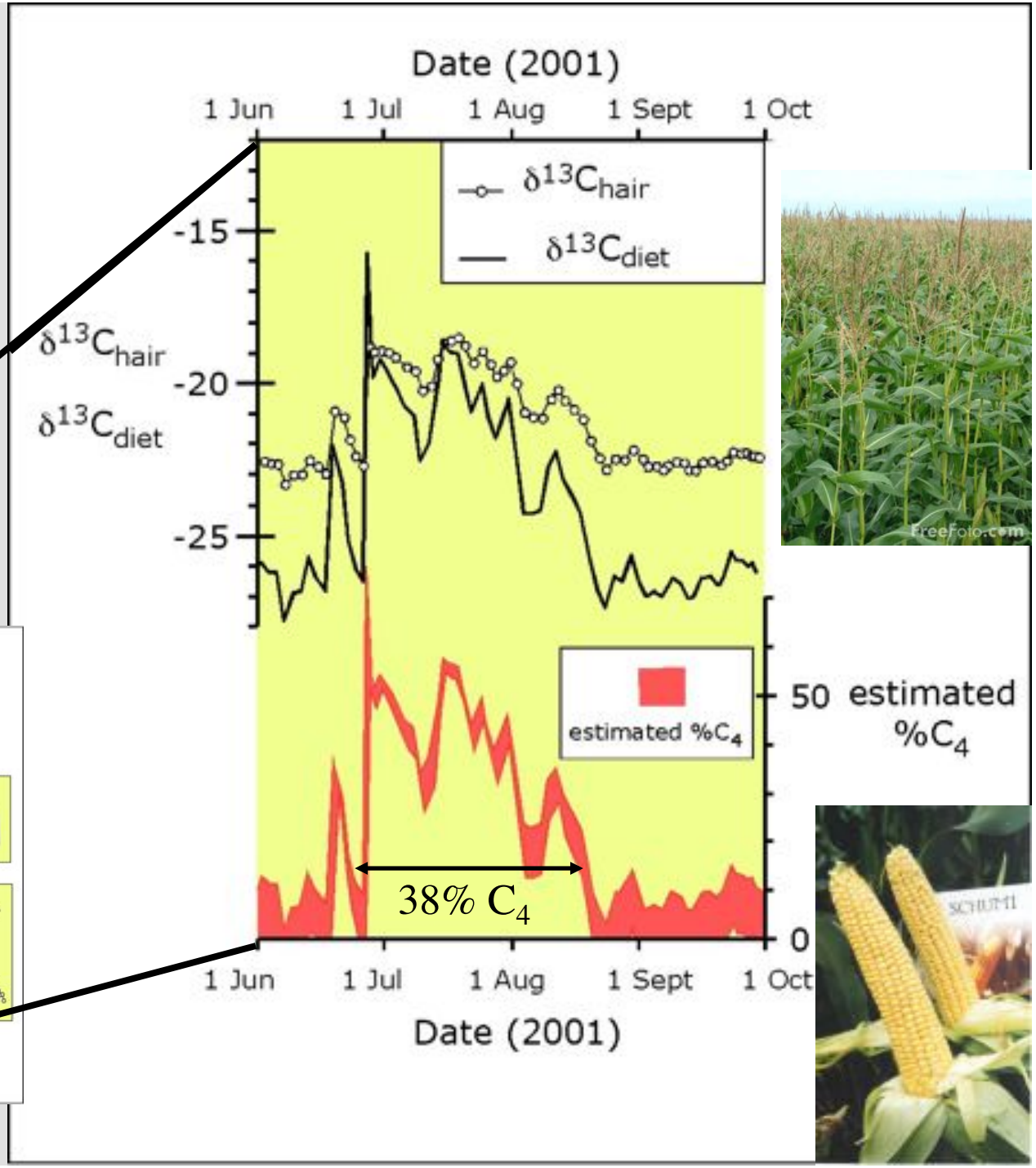
Crop raiding by Lewis occurs at night: outside the Imenti Forest



Detail of Lewis: June- Oct 2001

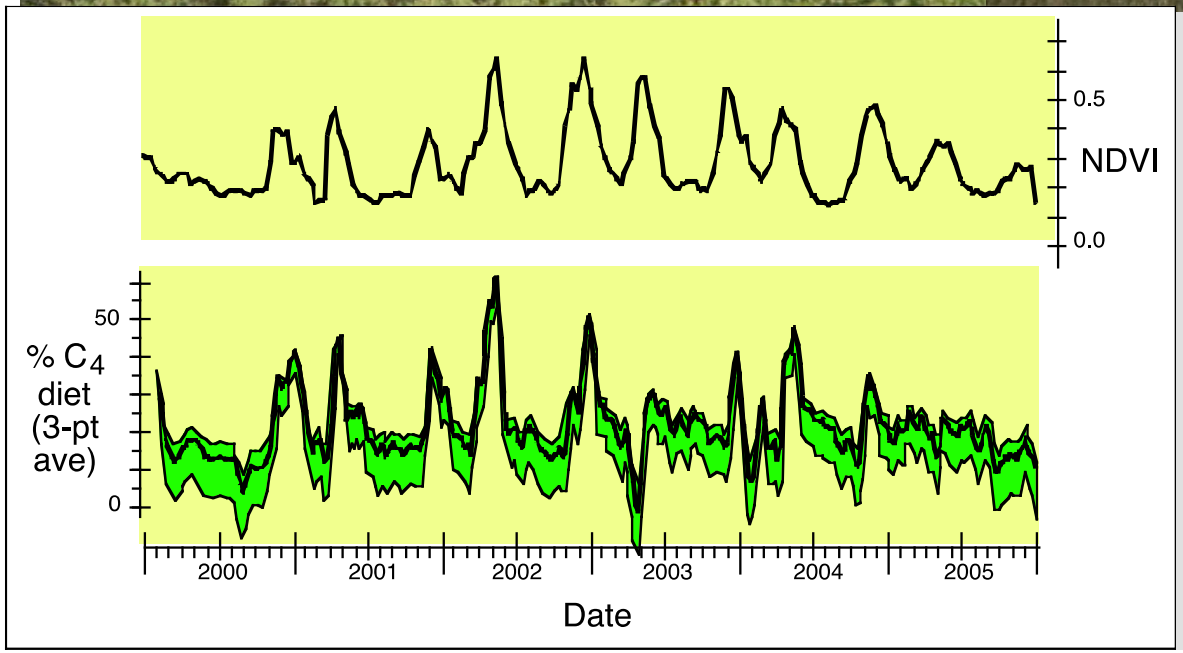
- Quantification of crop raiding

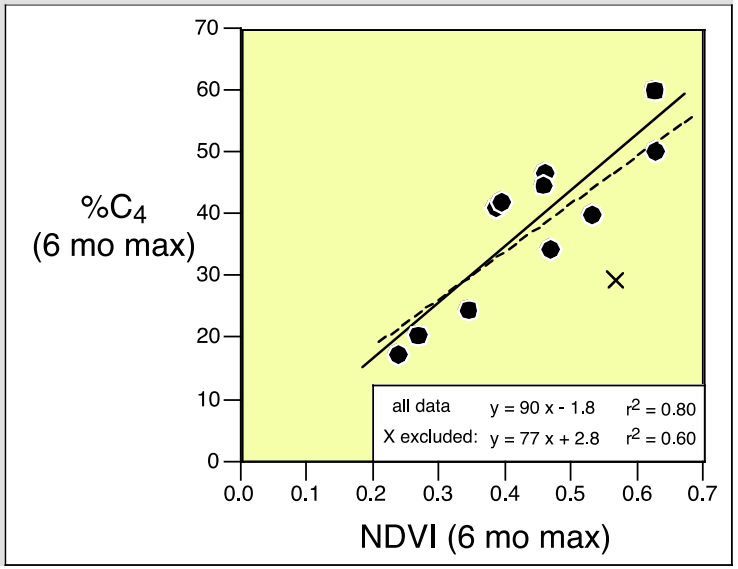




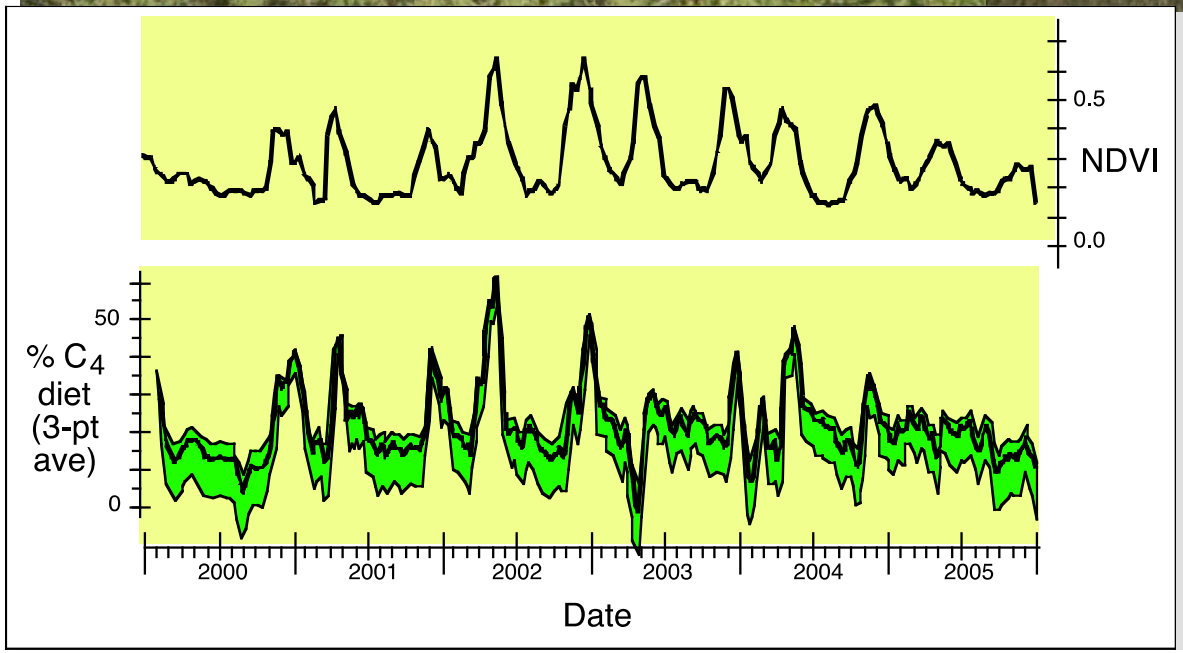
-Cerling et al., 2006

Diet, climate change, land-use change

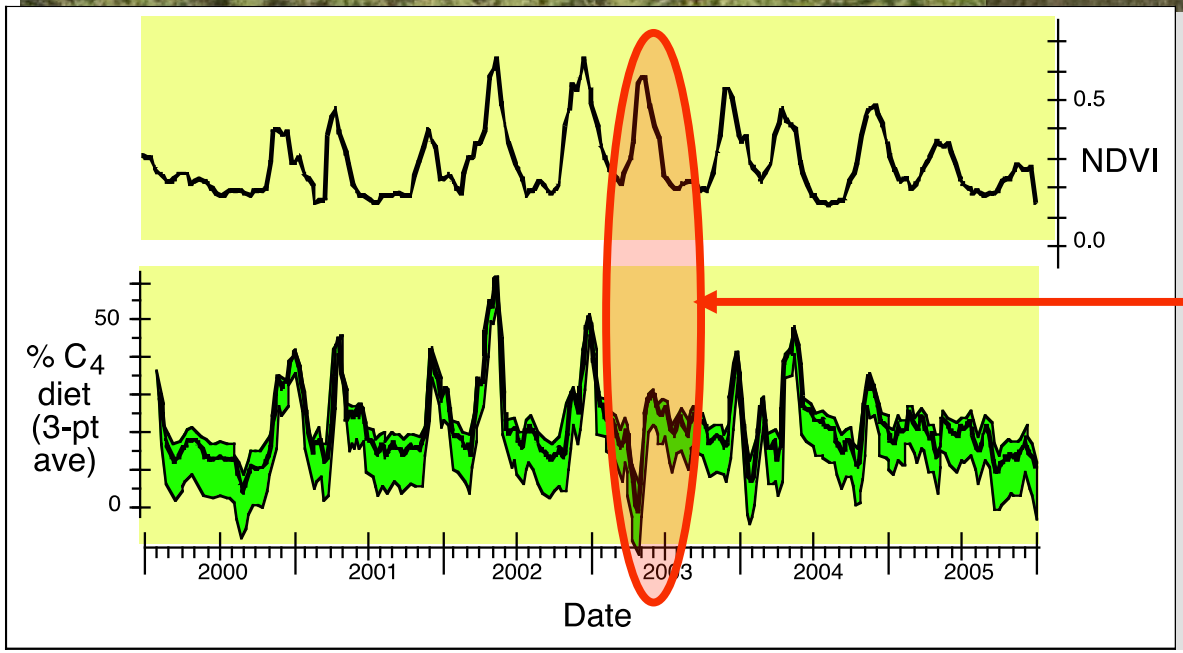




Predicting behavior (diet)

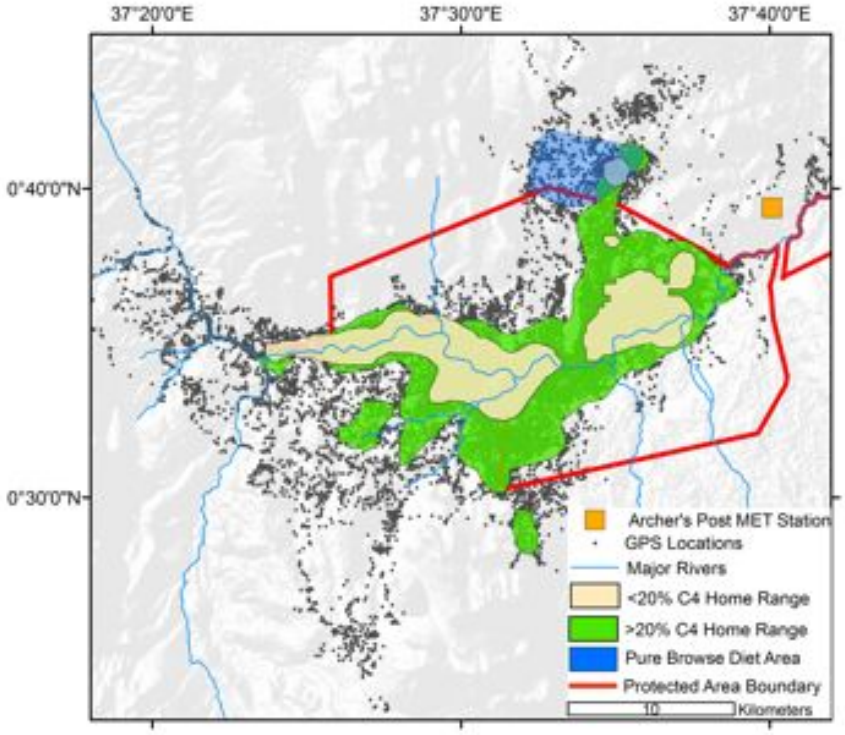


Diet,climate change, land-use change

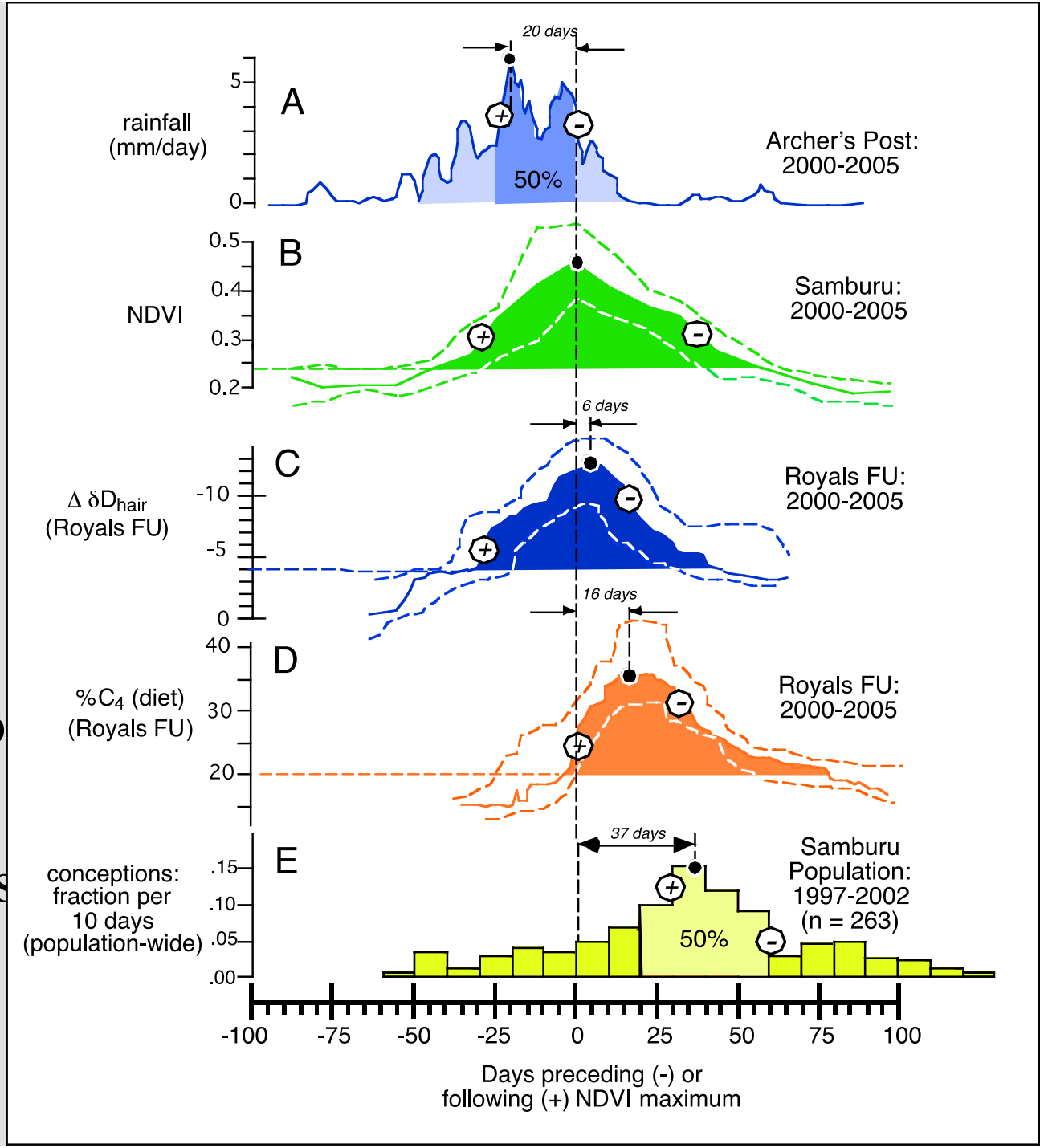


So what happened here?

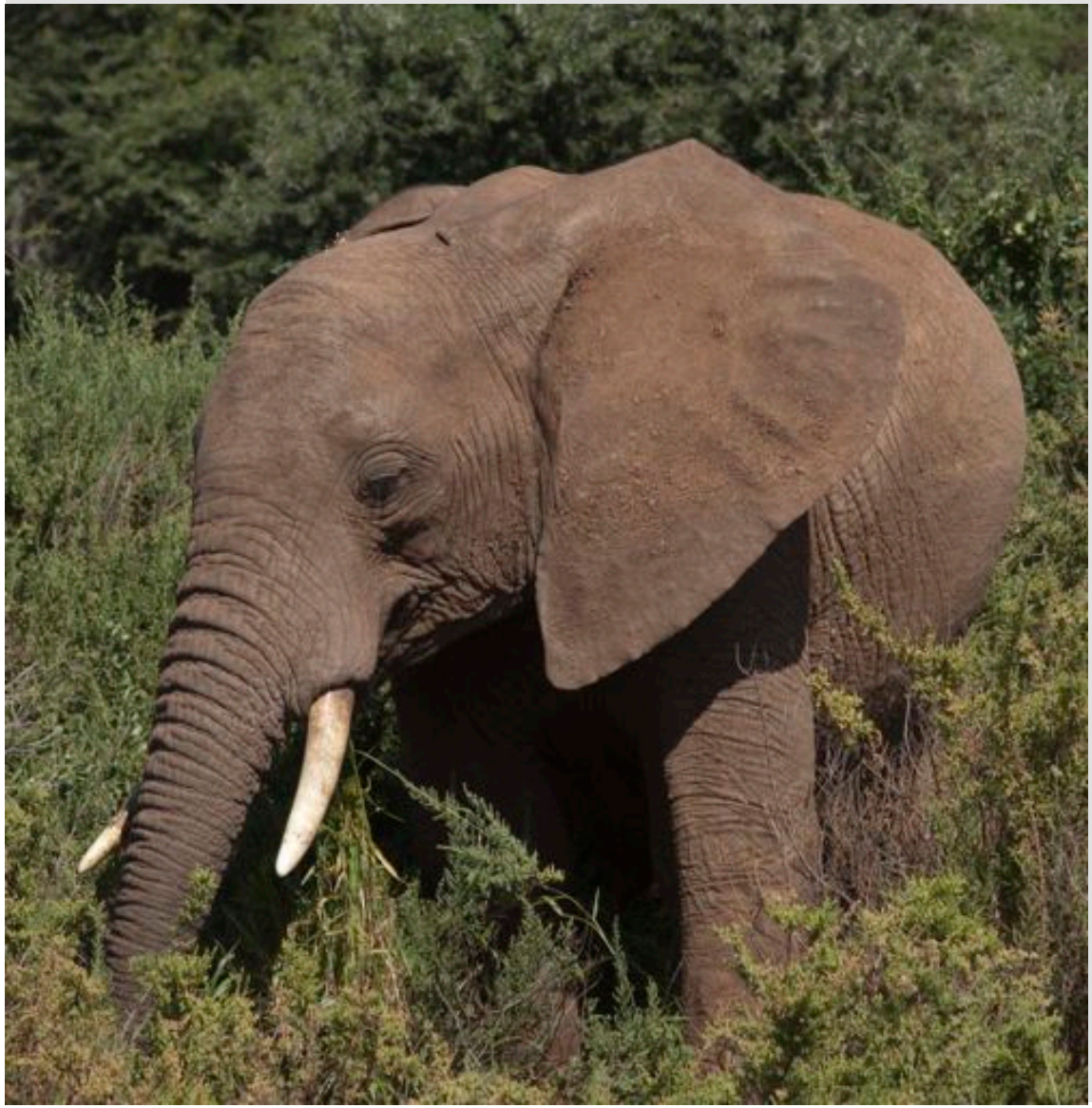
GPS tracking shows they left the park and were in community lands where they cannot compete with cattle: the grass is too short!



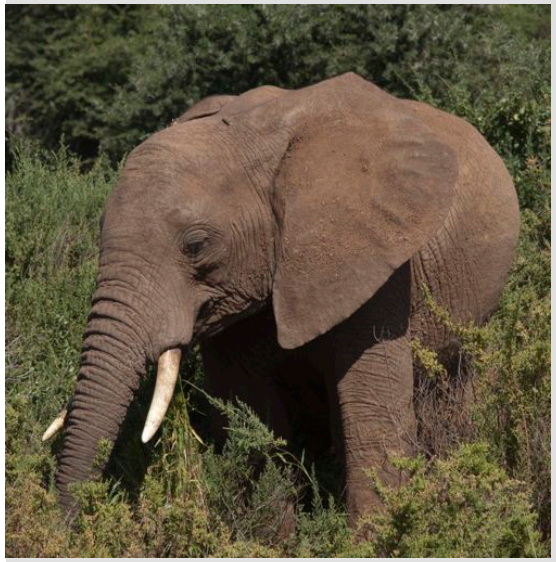
- Stable isotopes document the timing and progression of
- A. Rains
- B. Net Primary Productivity
- C. Water availab
- D. Diet respons
- E. Fertility



How do hair and ivory compare?



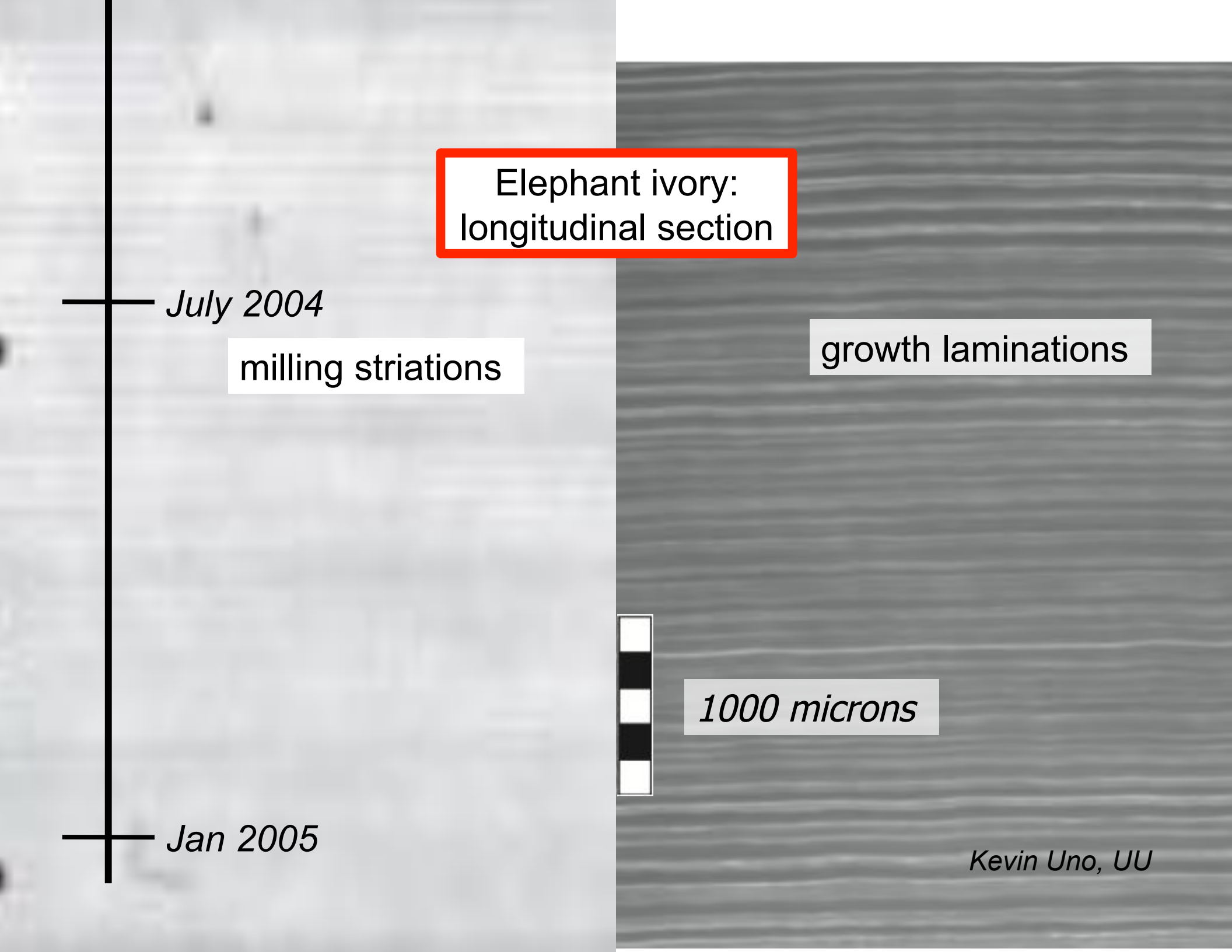
Other tissues? Compare hair and ivory.



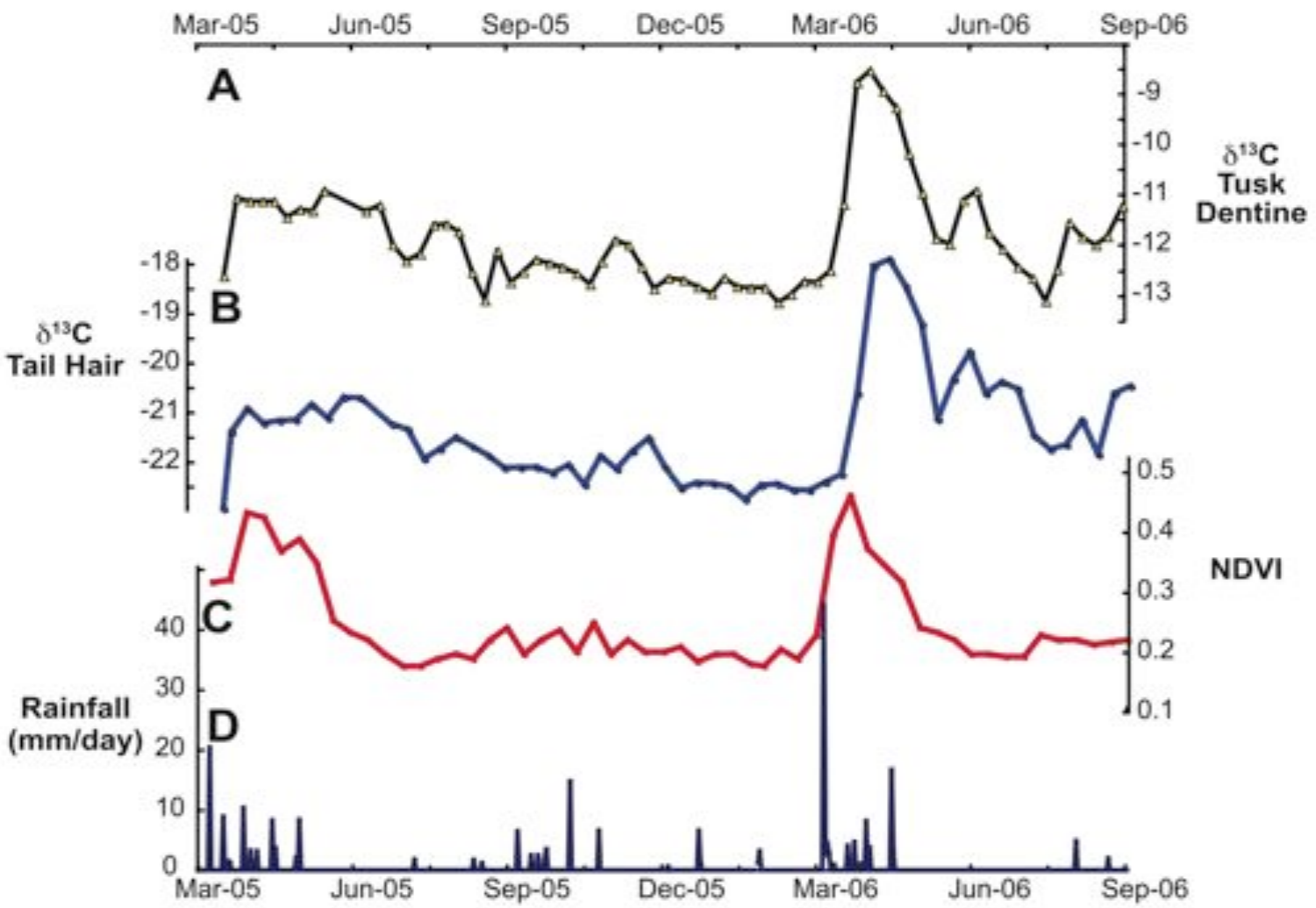
- Amina: d. 27 Sept 2006
  - Tusk. 27 Sept 2006
  - Molar (M6). 27 Sept 2006
  - Hair. 27 Sept 2006; 16 June 2006; 1 Nov 2002; 4 Feb 2002; 25 Jan 2001
  - GPS. 25 Jan 2001 to 27 Sept 2006 (intermittent)

Kevin Uno, UU

Misha: d. 9 Sept 2008
- Tusk. 9 Sept 2008
- Molar. M5 and M6
- Hair. None
- Travel. Moved from Vallejo CA to Salt Lake City UT 22 April 2005


Elephant ivory:
longitudinal section
July 2004
milling striations
growth laminations
1000 microns
Jan 2005
Kevin Uno, UU

Amina:
d. 27 Sept 2006



Kevin Uno, UU

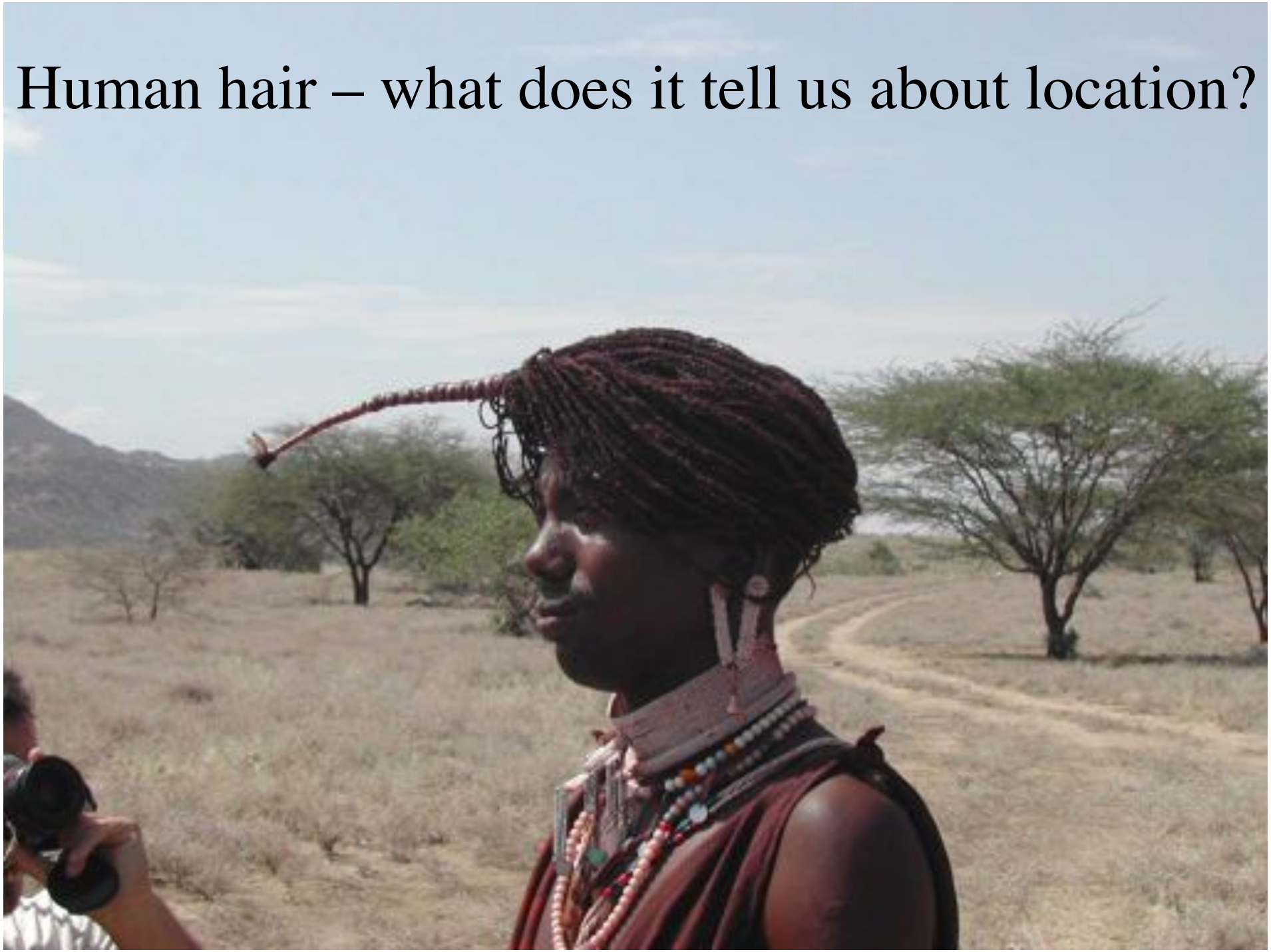
How do you collect collect elephant hair?

5 tons vs. 1½ ton
("curb" weights)

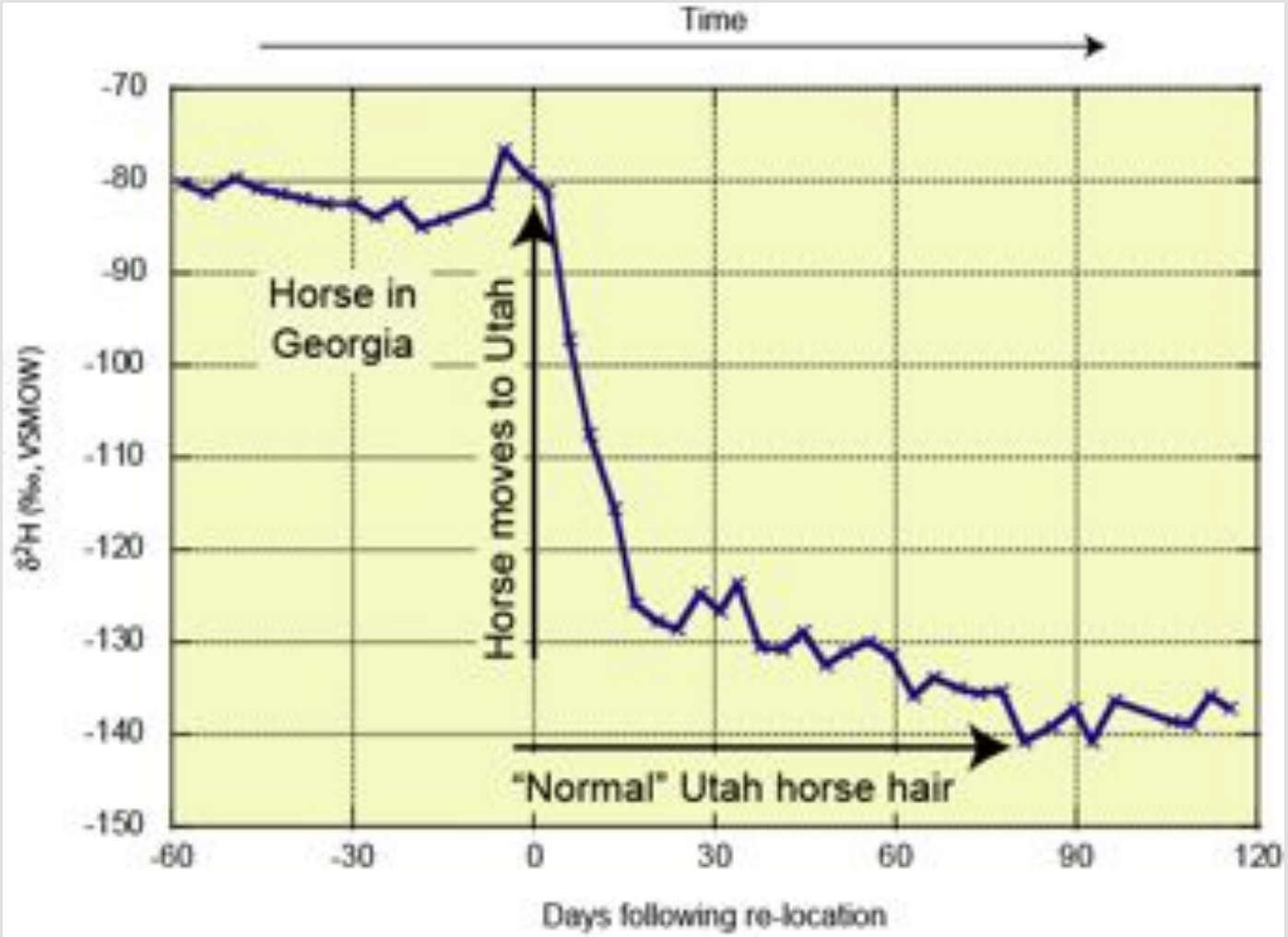
"Rommel"

George Wittemyer's
truck

Human hair – what does it tell us about location?

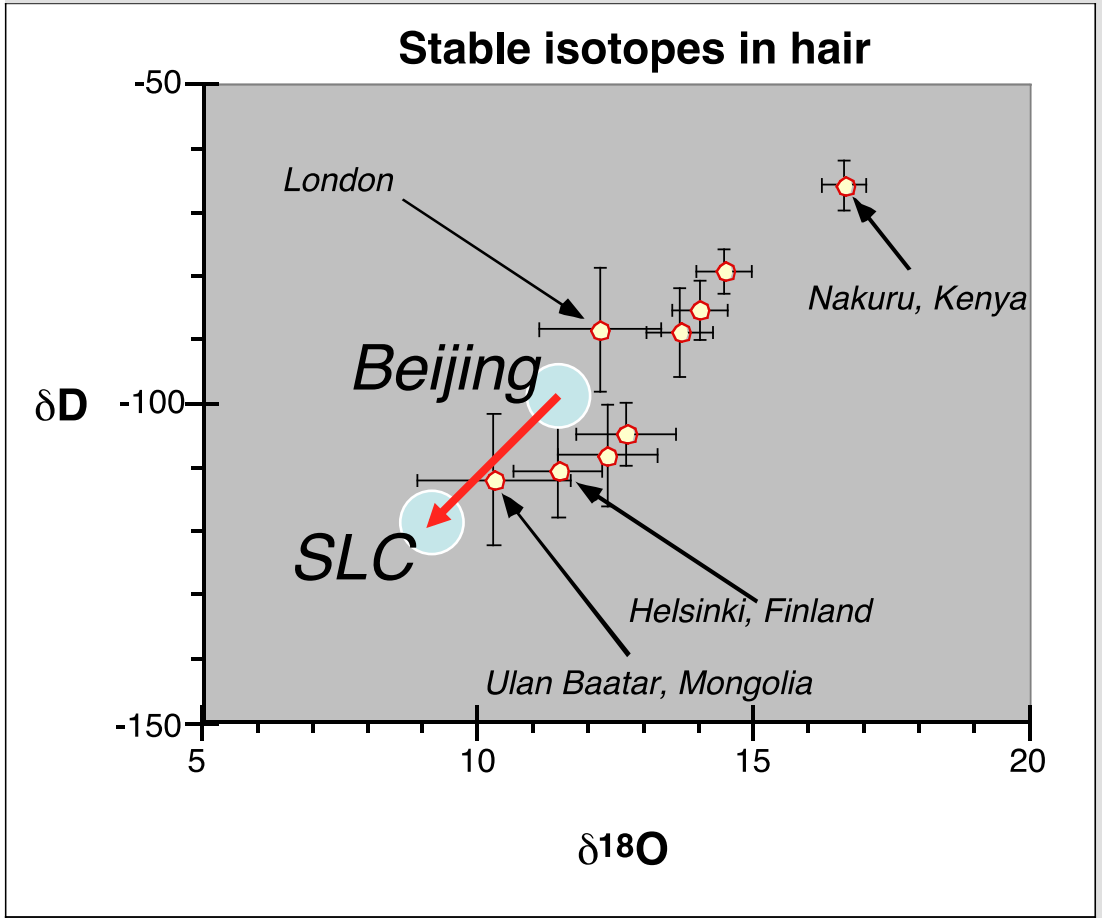


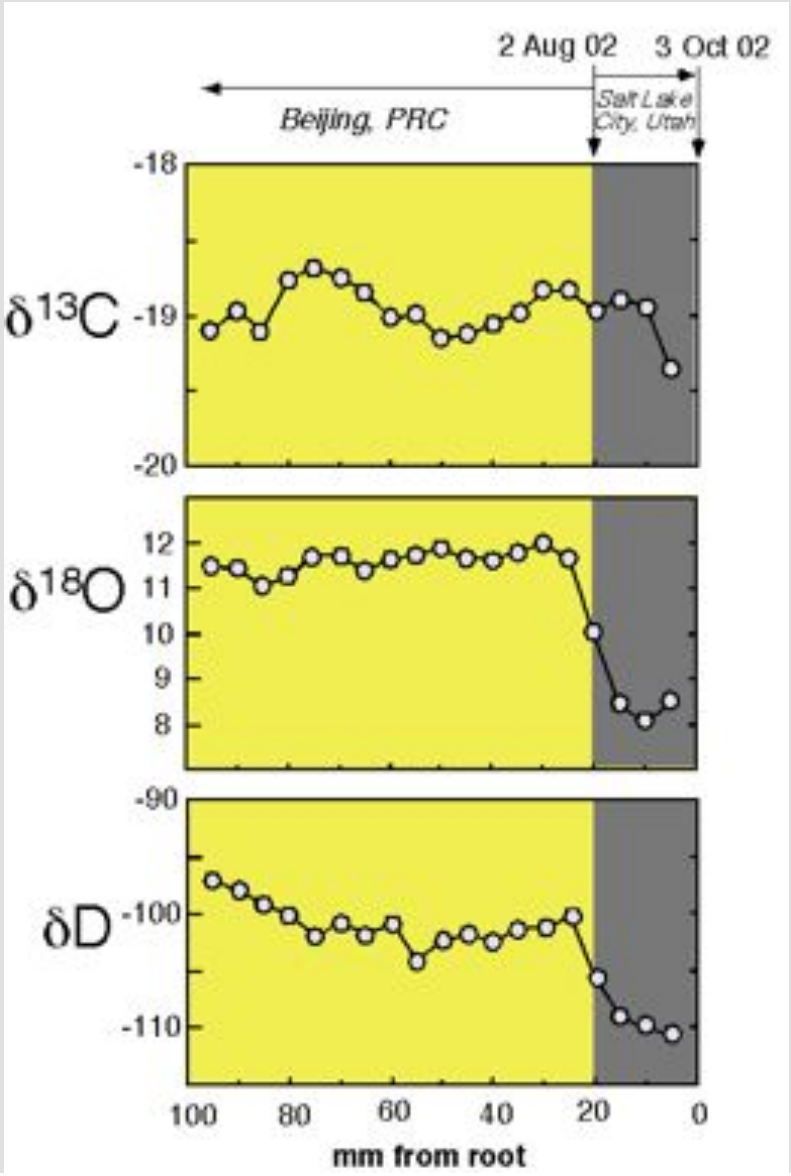
What is response to change in location?



Change in location recorded in a single hair. (Beijing to Salt Lake City).

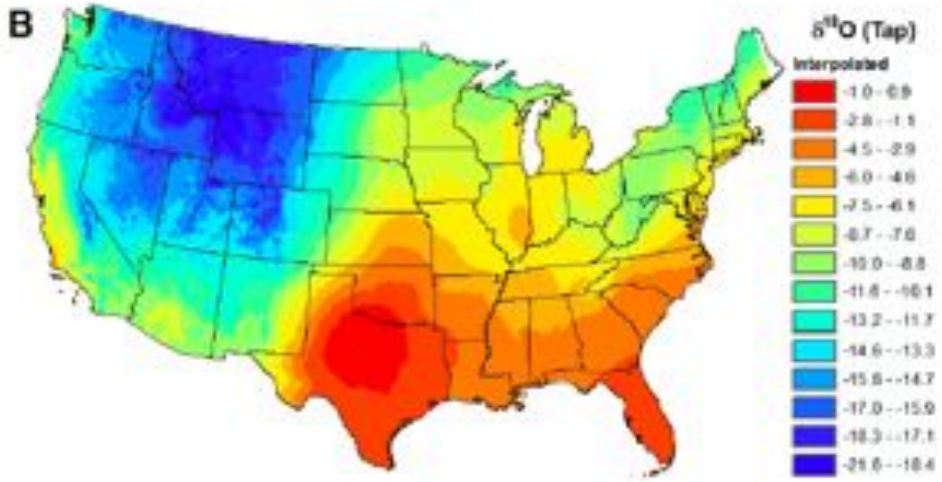
- *Residents of different cities have characteristic isotope ratios in their hair*





USA Tap Water Map $\delta^{18}O$,

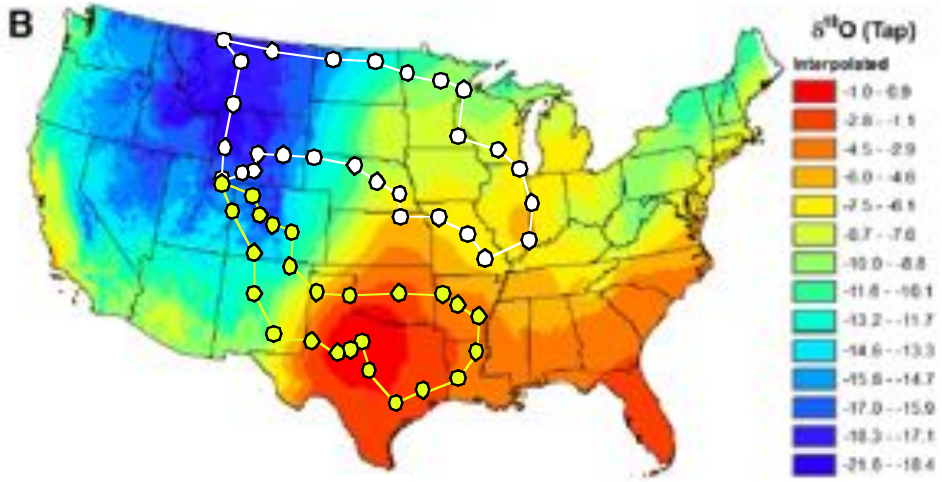
Bowen et al., 2007



Tap water "isoscape" based on > 1000 municipal water supplies

USA Tap Water Map $\delta^{18}O$,

Bowen et al., 2007

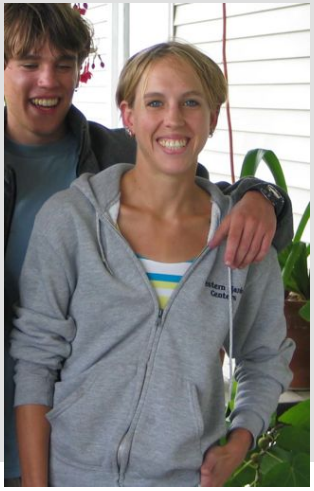


Tap water "isoscape" based on > 1000 municipal water supplies

Differences in the naturally occurring stable isotopes of water are "inherited" by local people in their hair

Dylan Cerling

Claire Cerling



Edna Ehleringer

Photos by Claire Cerling


OPEN

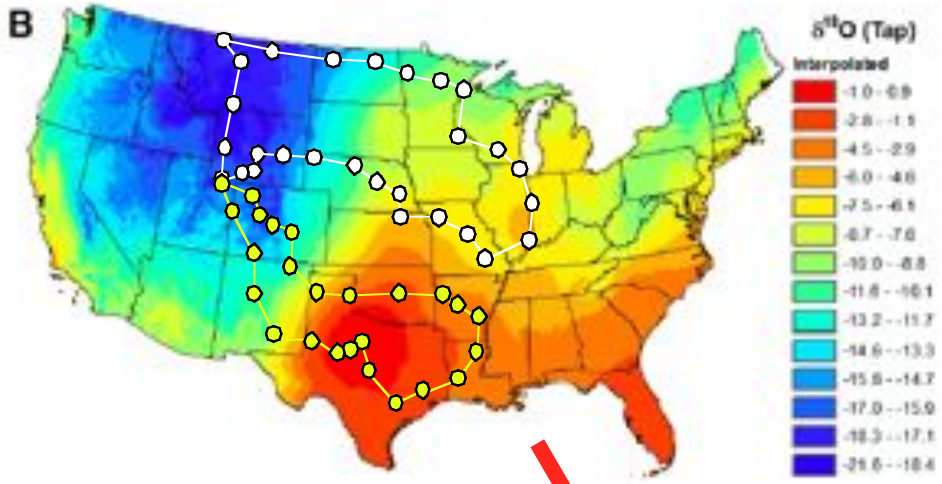

L & J's
Barber Shop
782 EGZ
341 KSG


FACTORY TOURS
BARRELS of FUN
WINE TASTING


BARBER
SHOP
516
OPEN

USA Tap Water Map $\delta^{18}O$,

Bowen et al., 2007



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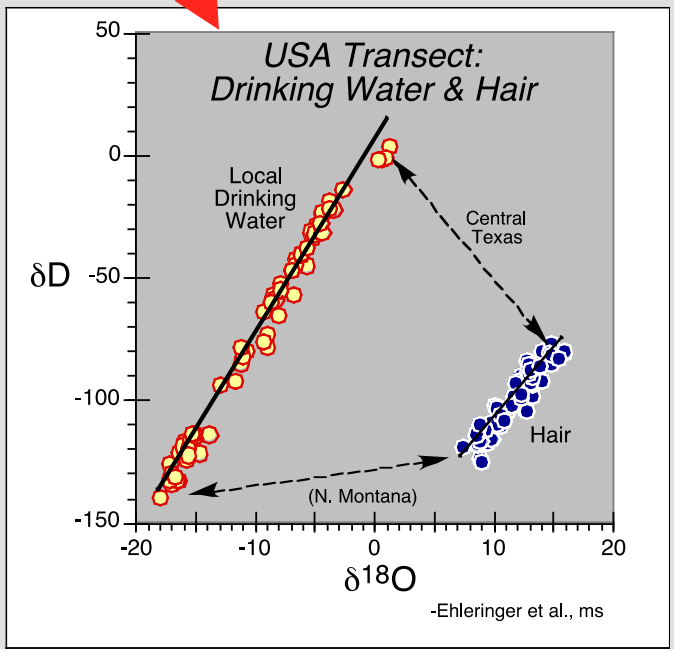

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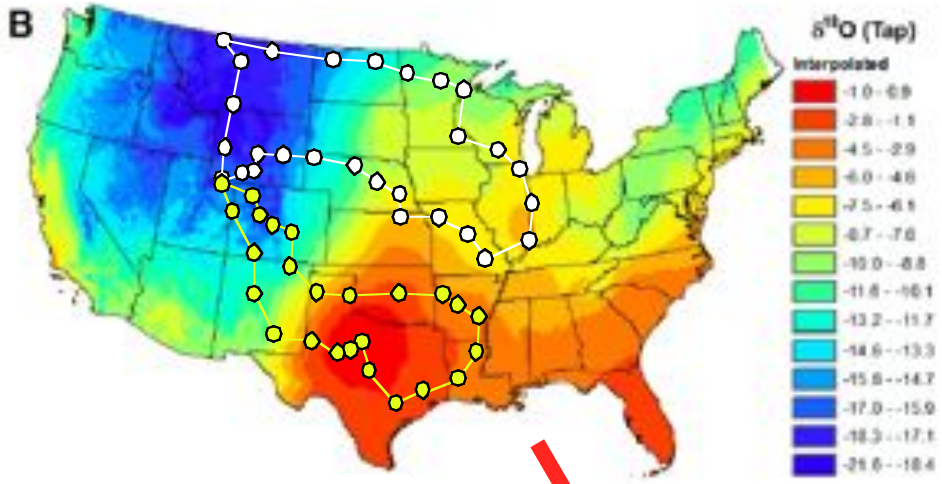

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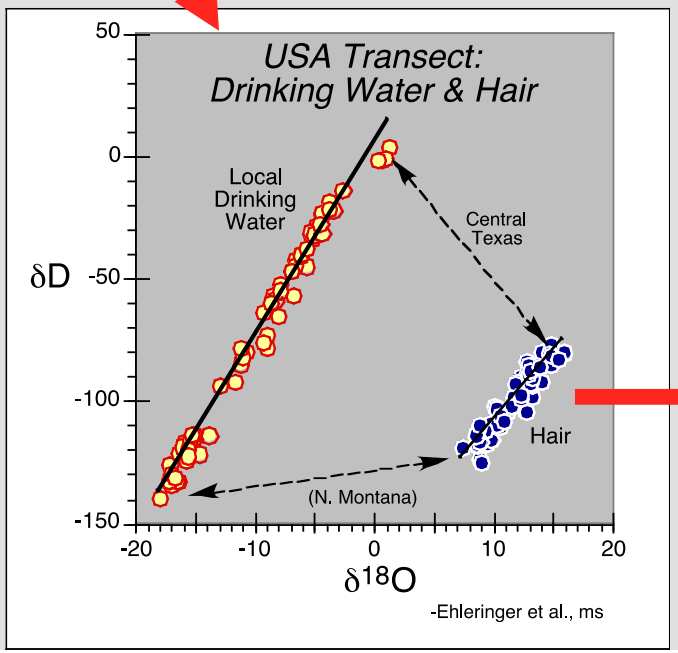
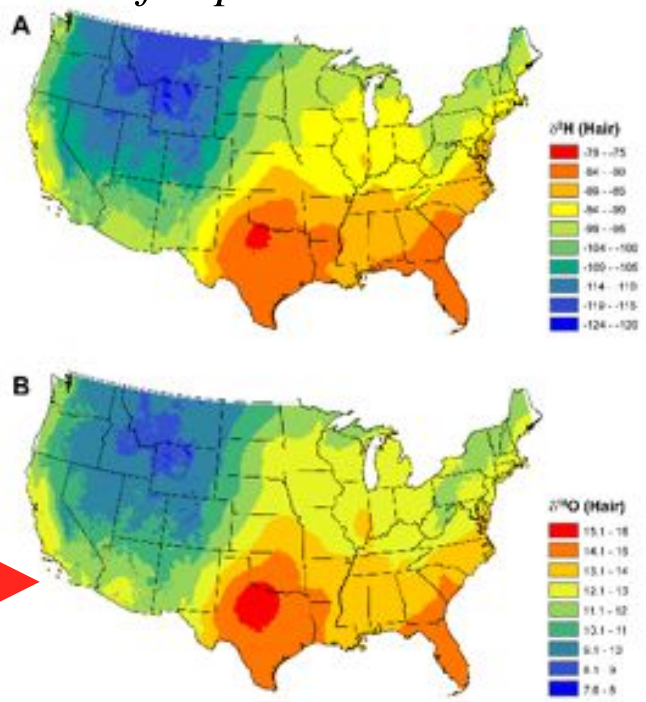


Human hair maps for provenance

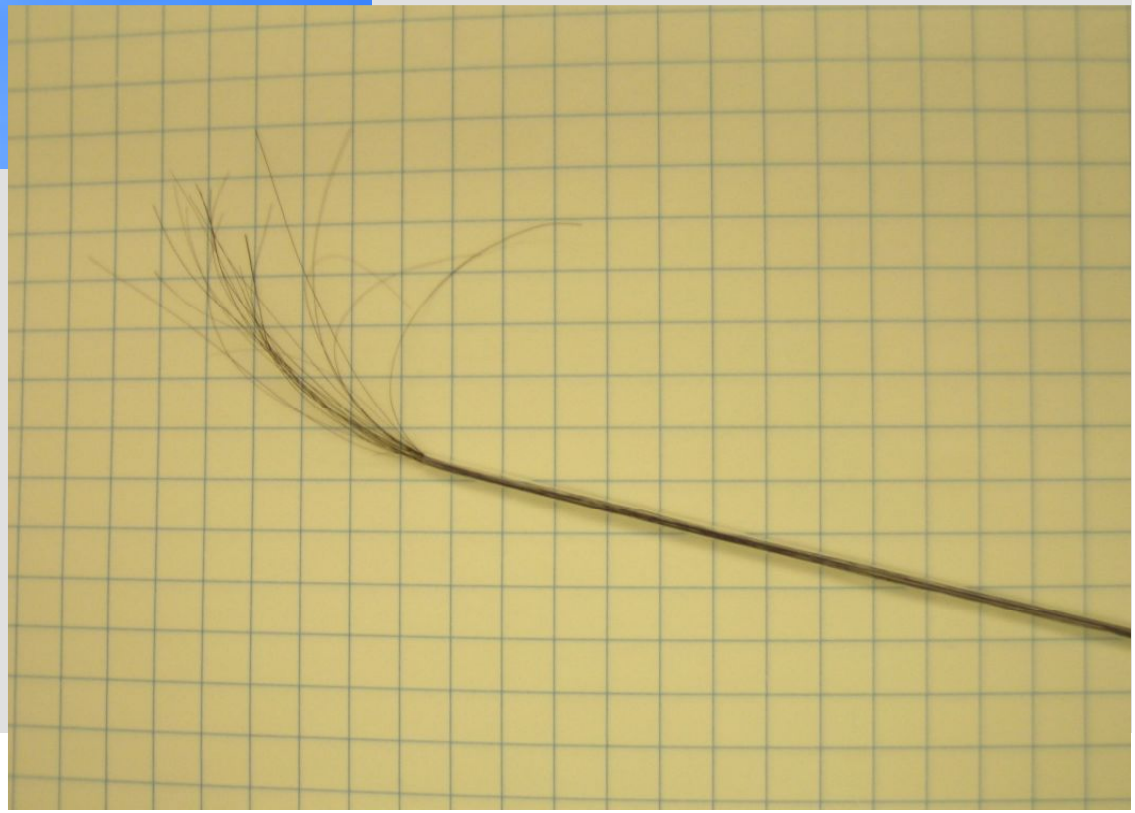


-Ehleringer et al., 2008

"Saltaire Sally"

A local "cold case"

Hair, skull, some bones were found near Saltaire, Utah



Bundling of hair: increases resolution by increasing sample amount

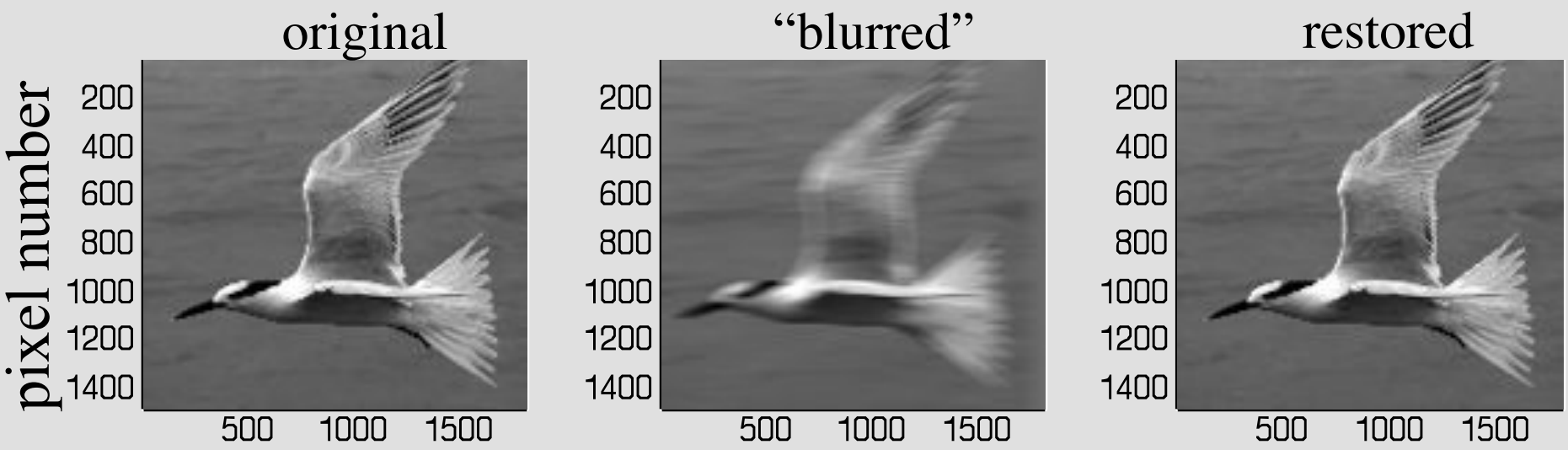
Decreasing resolution by "averaging" samples with different growth rates and in different stages of growth (anagen versus catagen-telogen).

Growth rates (*ca*. 1 cm per month) in humans varies by ca. ± 10%

Approximately 10% of hairs are in "resting stage".

Model that follows:

90% anagen stage	60 ± 6 months
10% catagen-telogen	6 ± 1 months

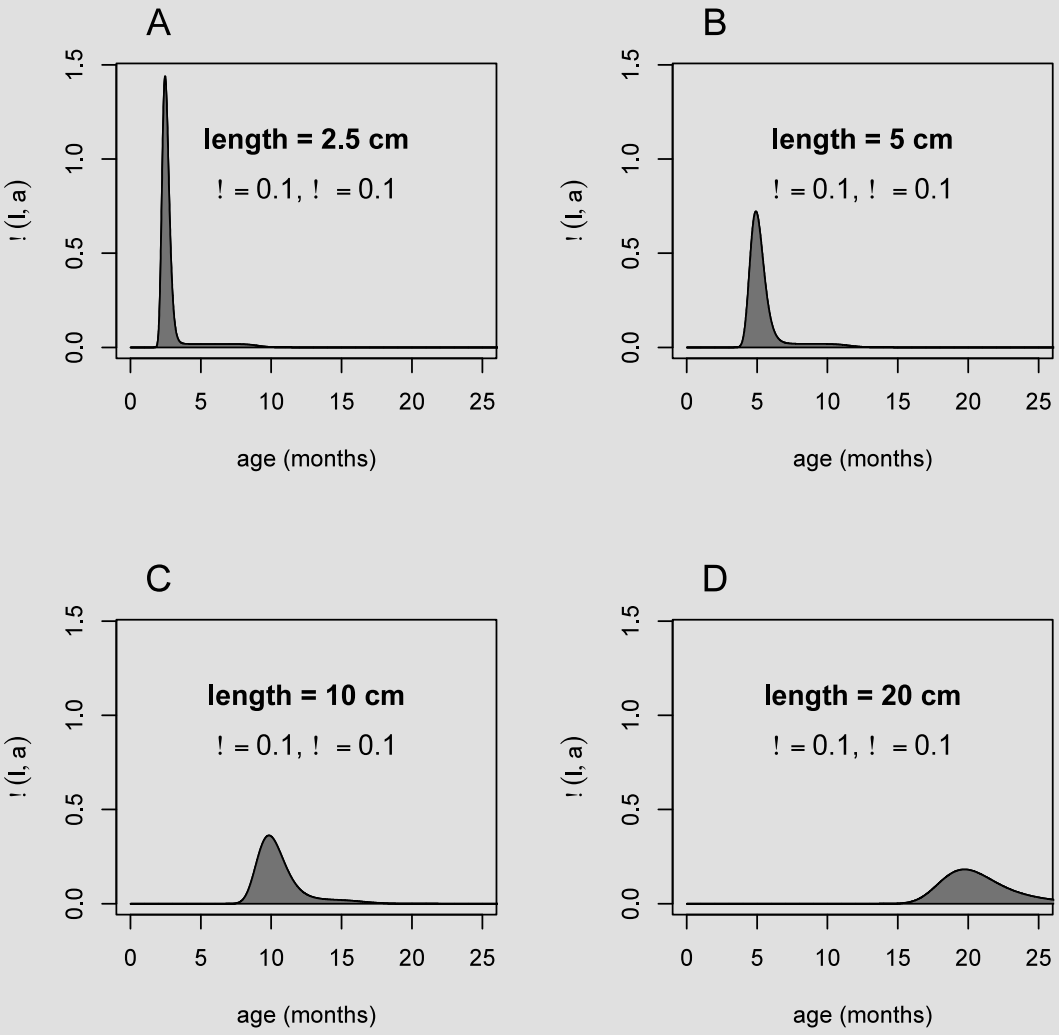


100-pt boxcar smoothing

-Menke, 2012

Hair Bundling (Remien thesis)

- Multiple hairs
- Gaussian distribution of growth rates and phases
- Signal increasingly "blurred" with increasing time

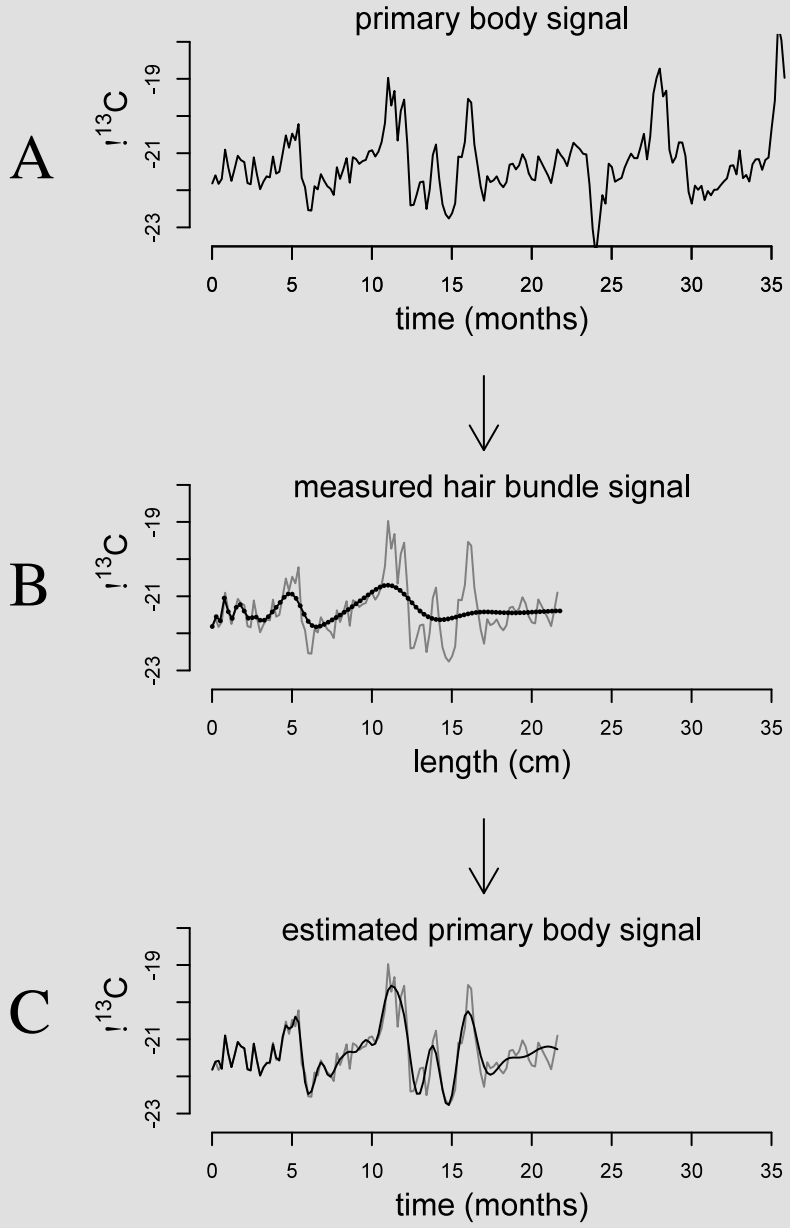


Signal recovered with inversion methods

but high frequency information can be lost

Example. high resolution record of elephant hair (*ca*. 3 years)

A. Original
B. Modeled: assume 10% growth rate variation
C. Deconvolution using inverse methods



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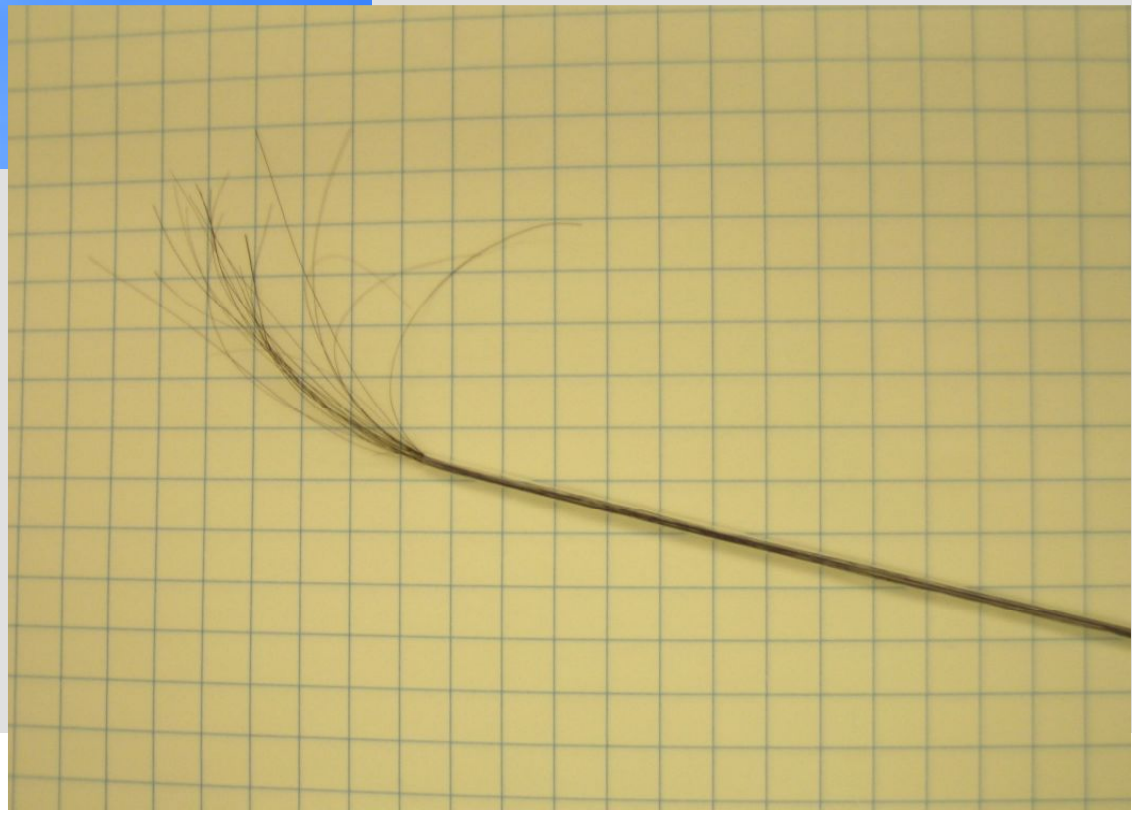
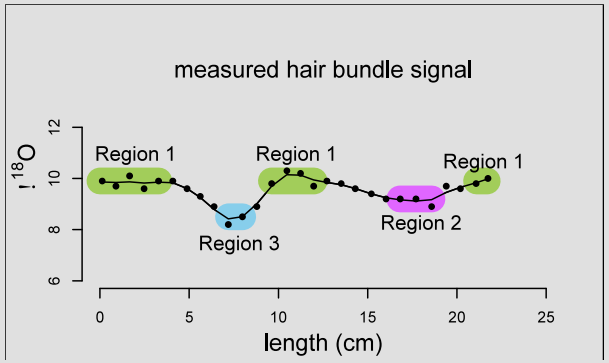
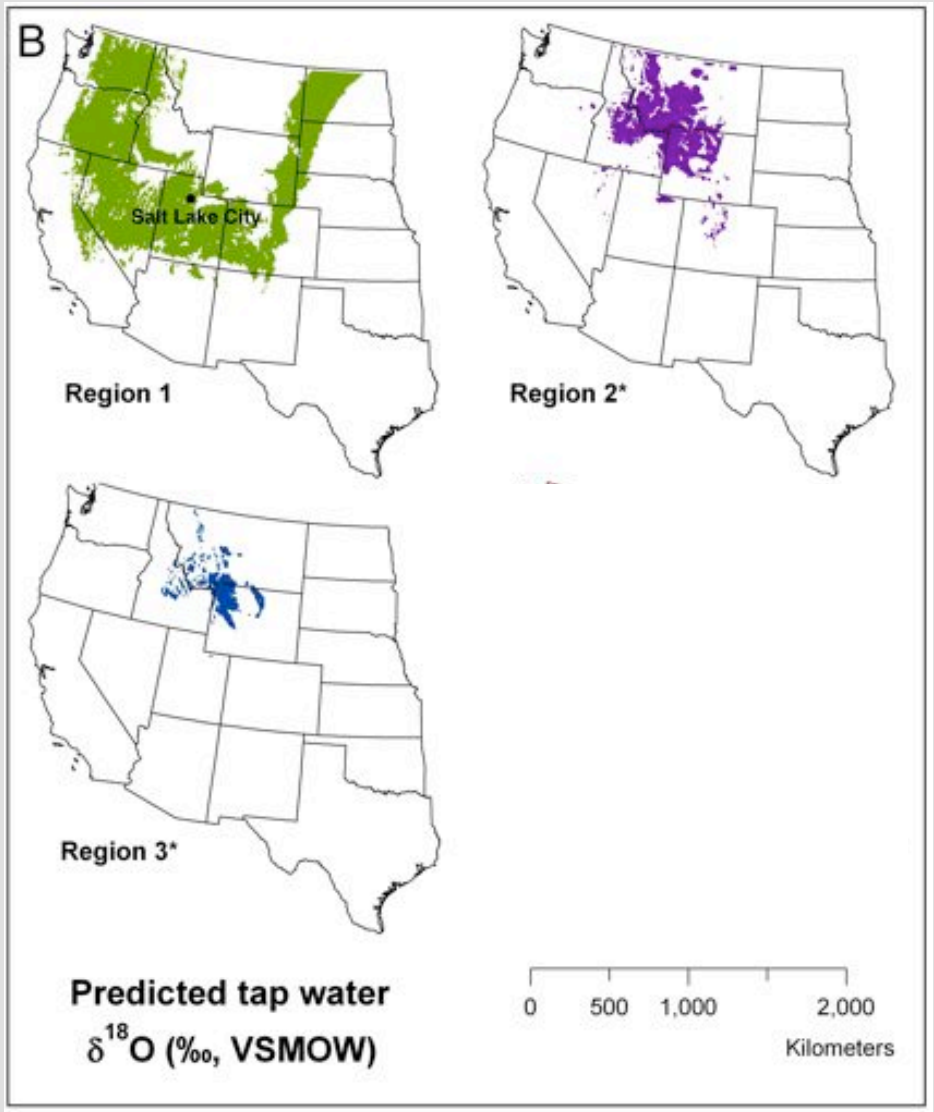
Hair, skull, some bones were found near Saltaire, Utah



Inversion and non-steady state suggests new search region for murder victim



Original interpretation:
Travel in N-S direction,
about every 6 months



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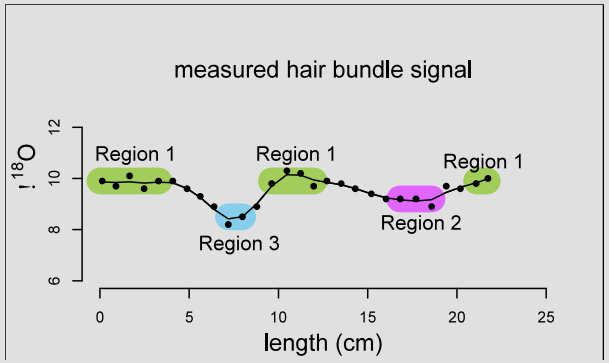

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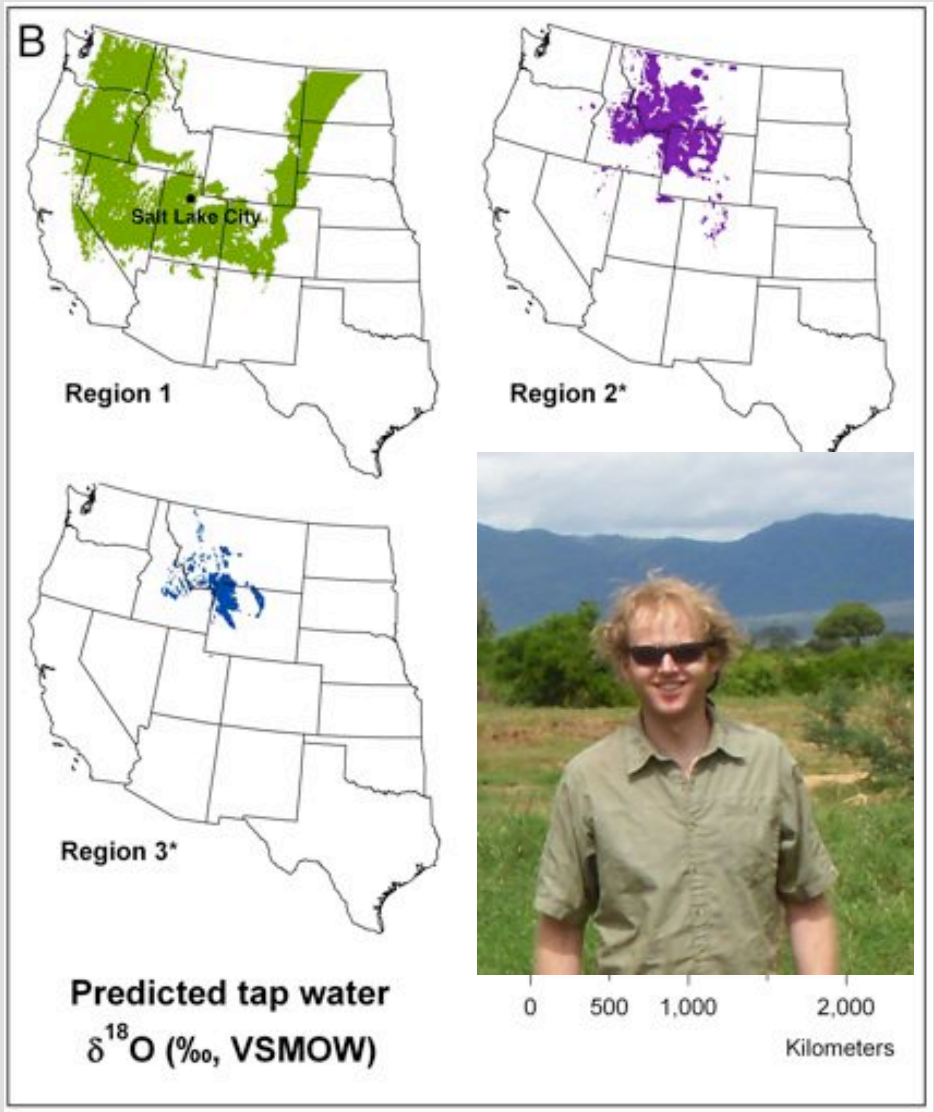

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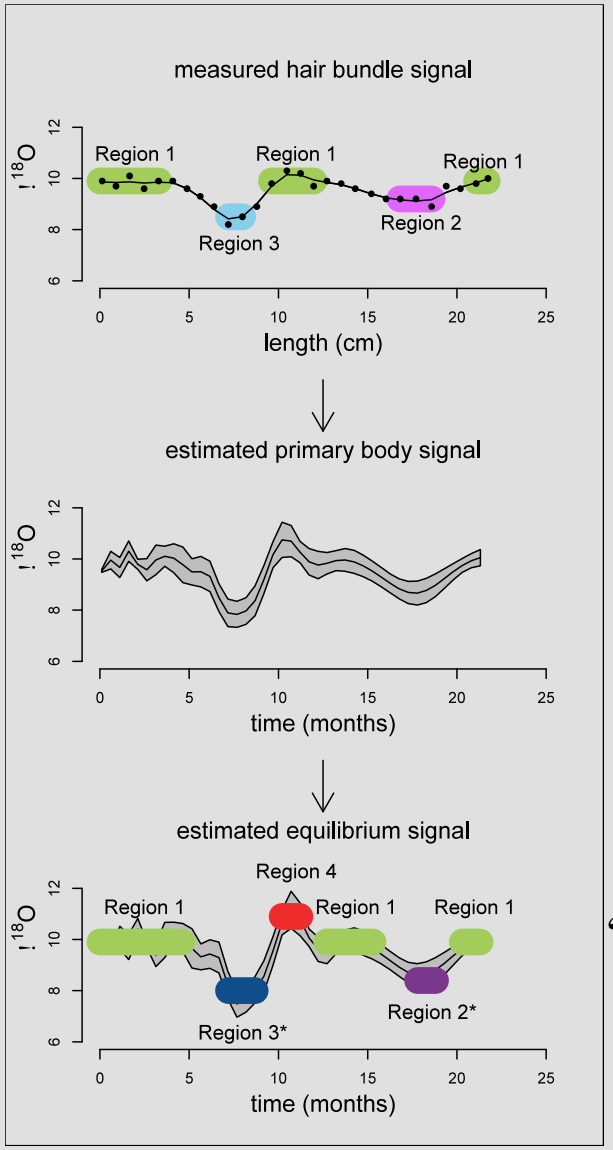
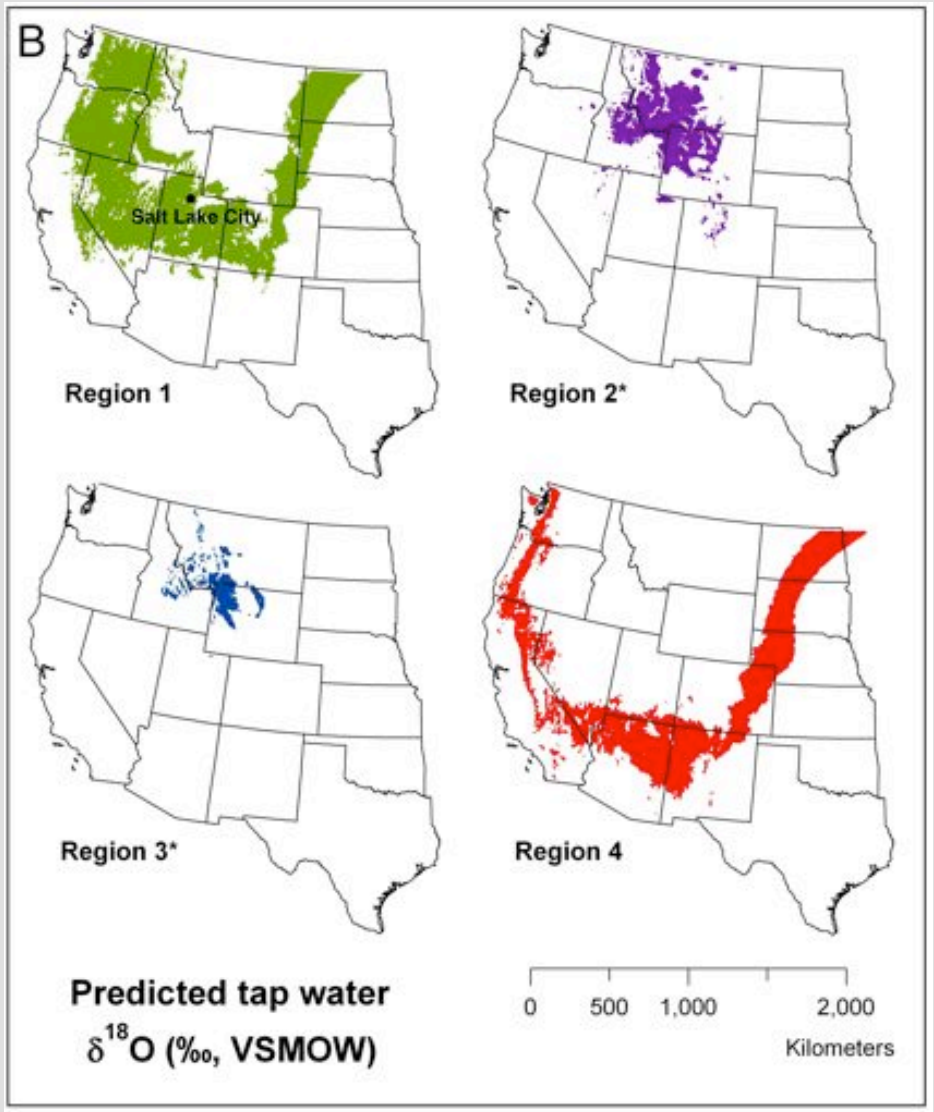


1. Inversion

2. Correct to "equilibrium"



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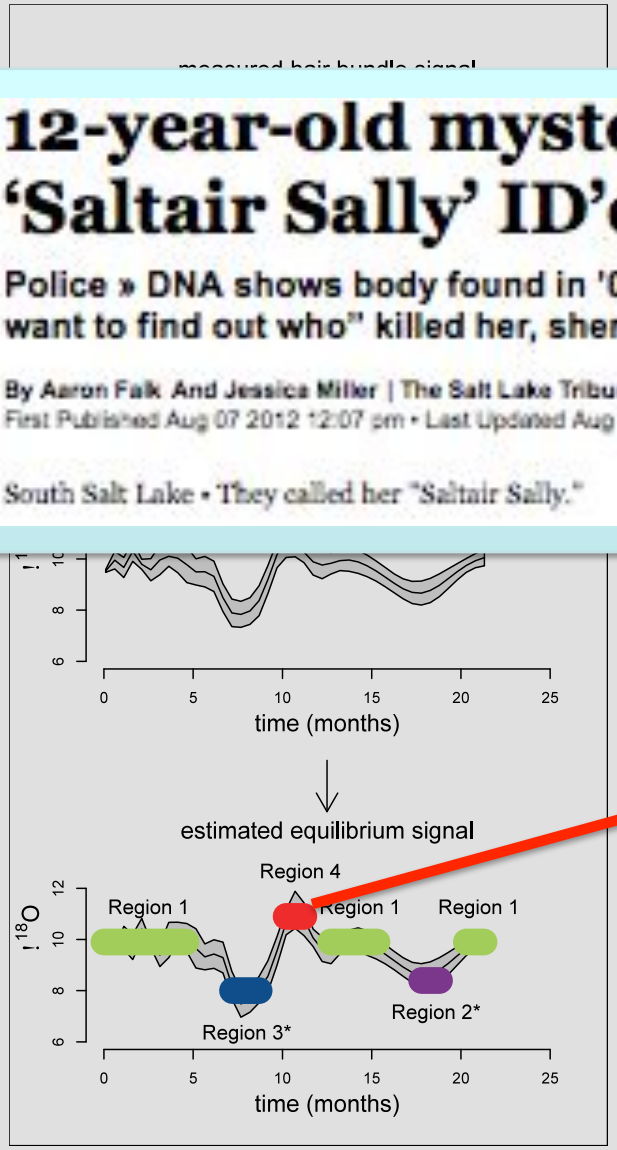
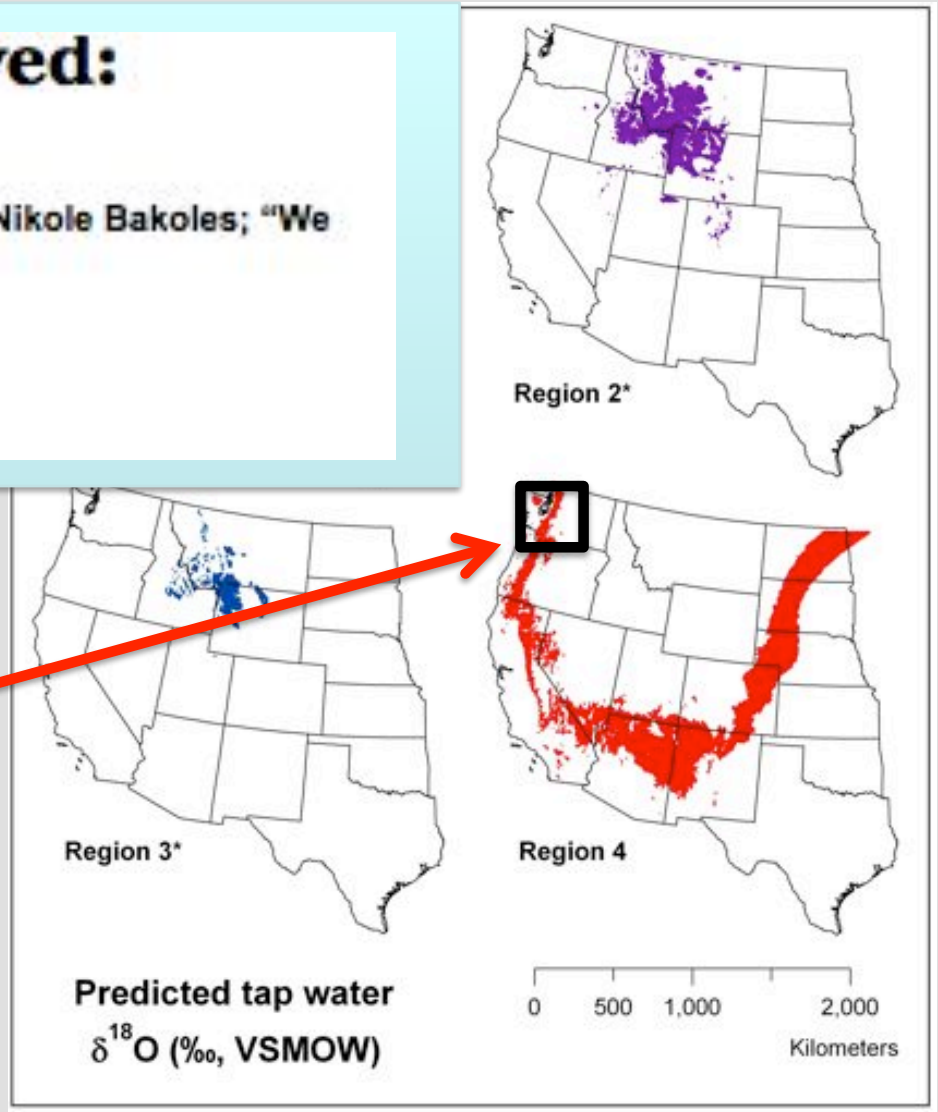


12-year-old mystery solved: 'Saltair Sally' ID'd

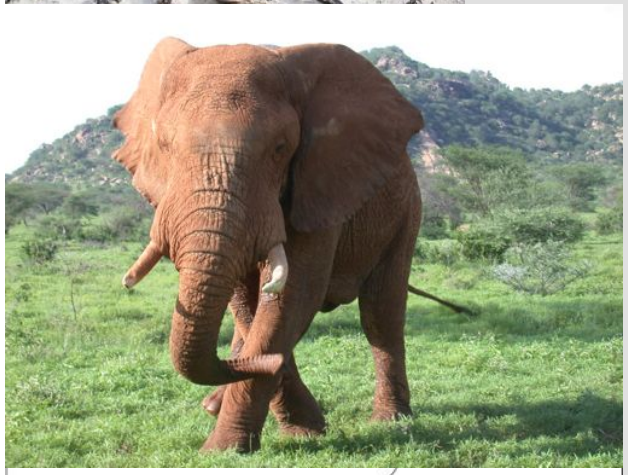
Police » DNA shows body found in '00 belonged to Nikole Bakoles; "We want to find out who" killed her, sheriff says.

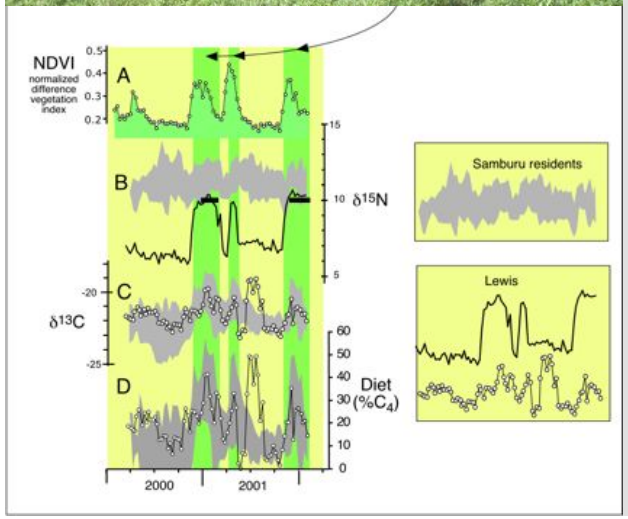
By Aaron Falk And Jessica Miller | The Salt Lake Tribune
First Published Aug 07 2012 12:07 pm • Last Updated Aug 08 2012 09:32 am

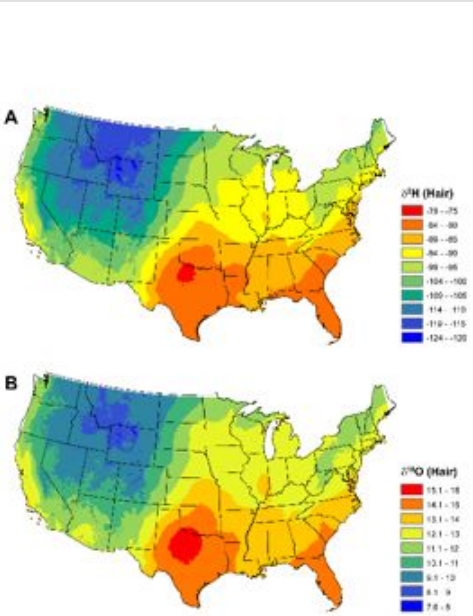
South Salt Lake • They called her "Saltair Sally."

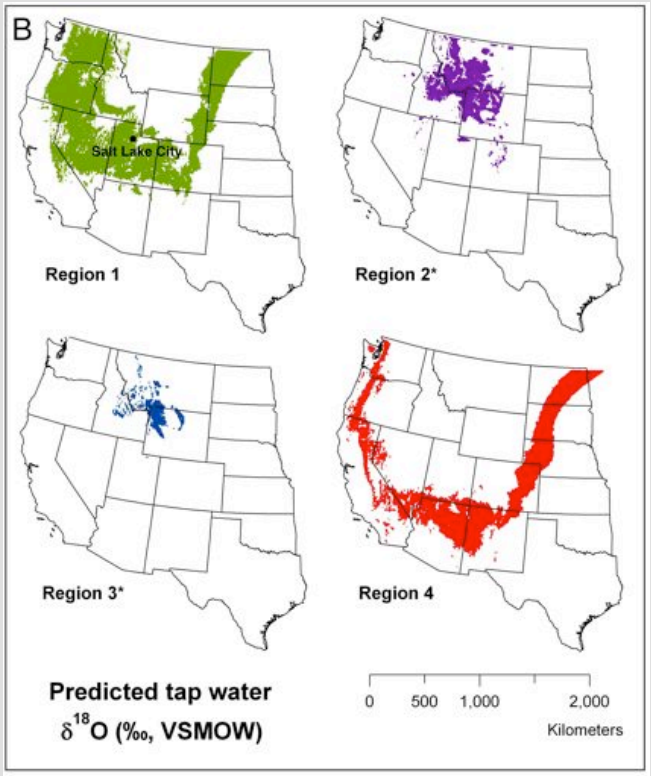


You are what you eat (+ a few ‰)



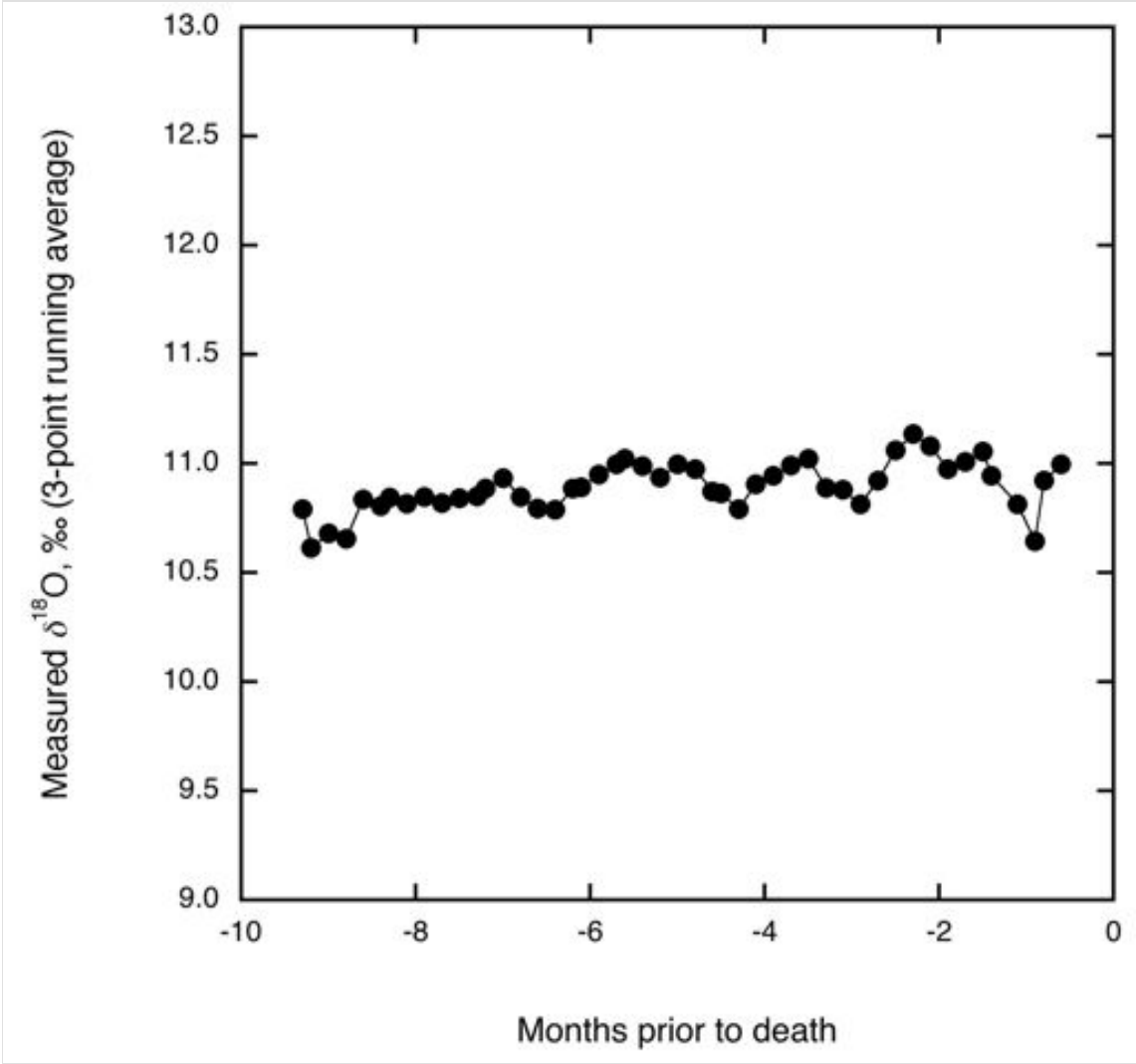






Backup

NCIS (A Cold case, re-opened in 2008)

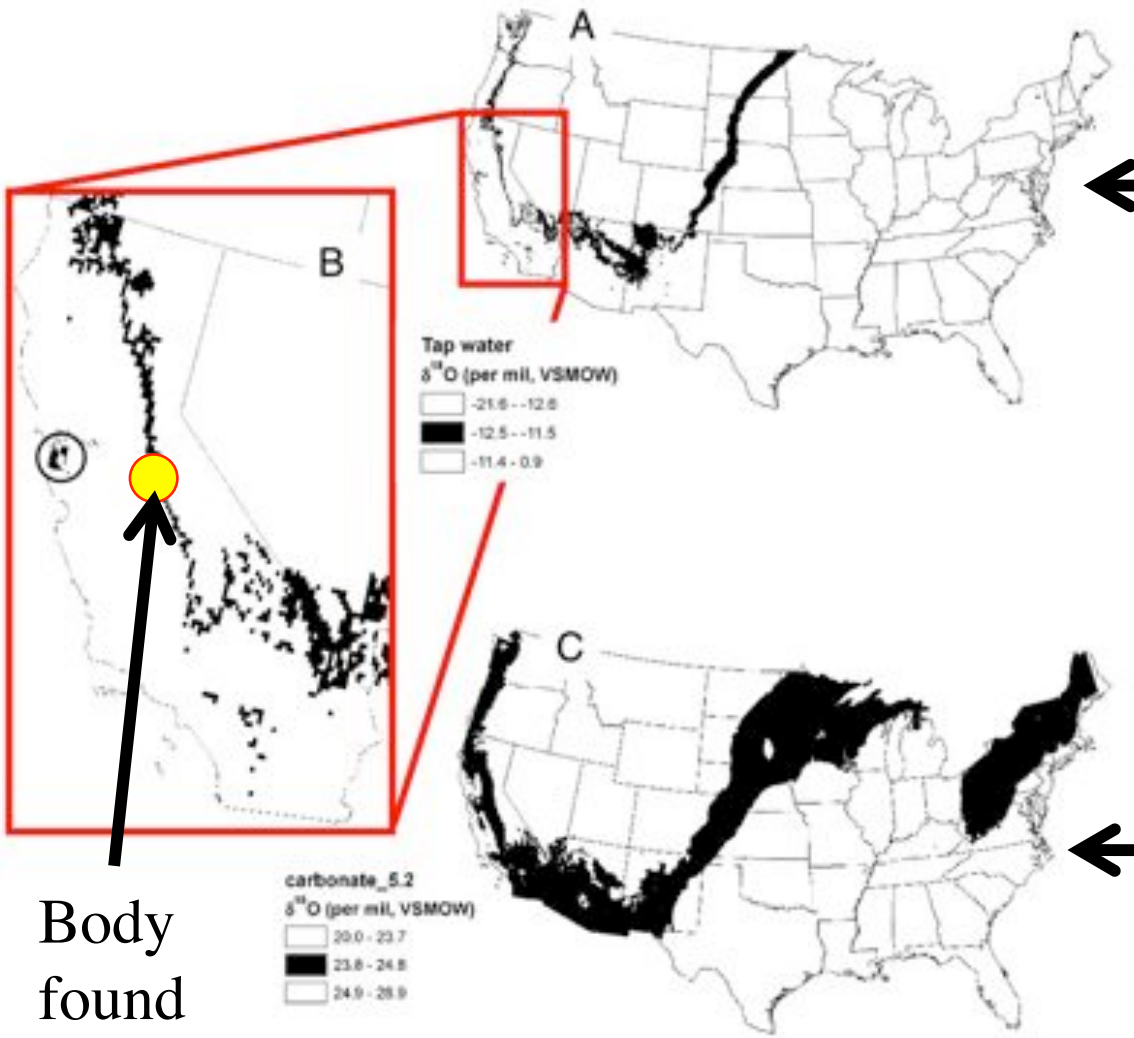


-Chesson, et al., in press

Hair from "Jane Doe", found in canal in Stanislaus County, CA on 11 September 1971 with 65 stab wounds.

Isotopes indicate limited travel in last year of life

Reconstructed travel history



Body found

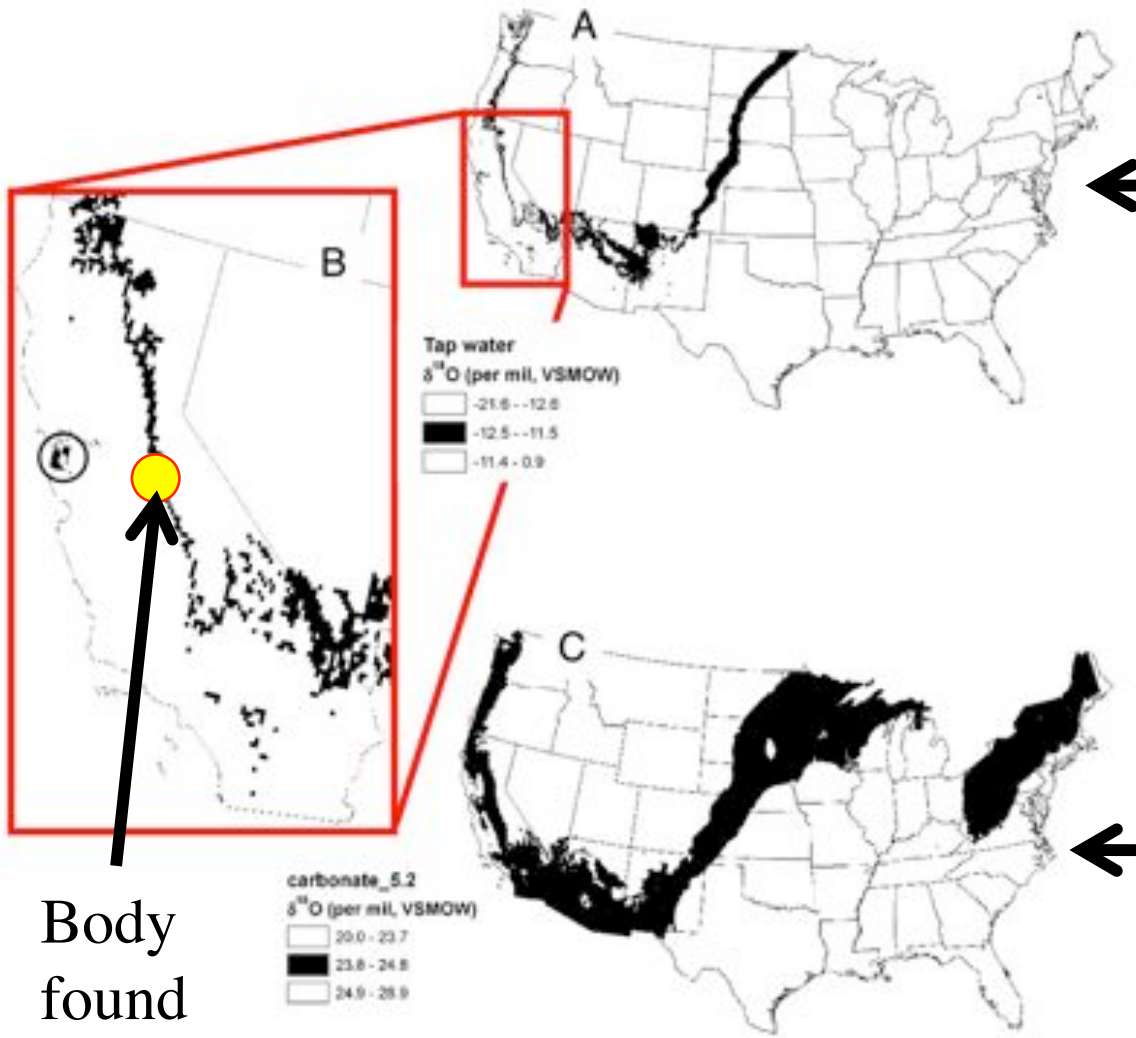
From hair
- last year of life
- *i.e.*, 1971

Who was this person?

From teeth
- *ca.* 6 years old
- *i.e.*, 1950

-Chesson, et al., in press

Reconstructed travel history



Body found

From hair
- last year of life
- *i.e.*, 1971

Conclusion: likely limited travel. Could be California resident

From teeth
- *ca.* 6 years old
- *i.e.*, 1950

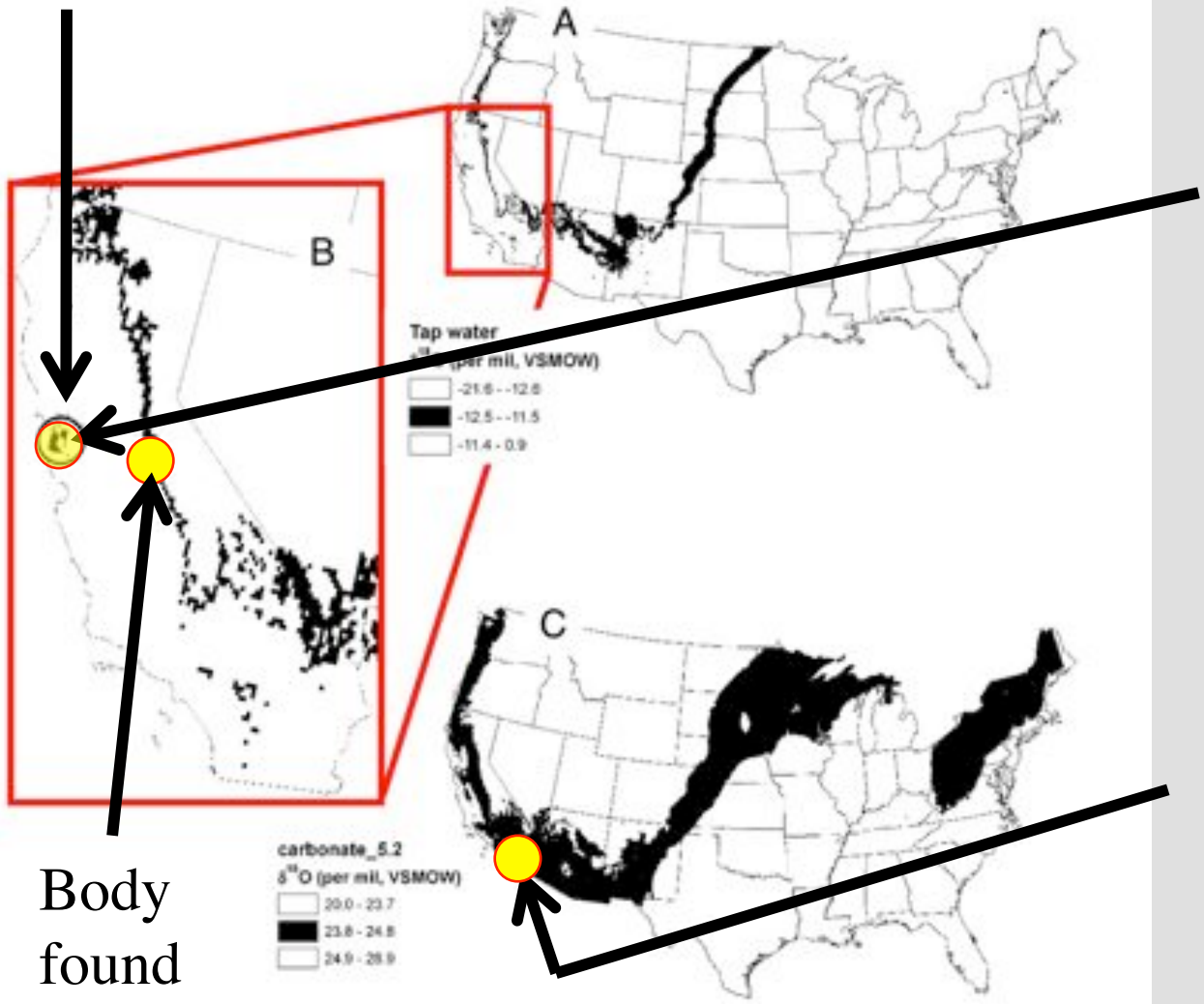
-Chesson, et al., in press

MARY ALICE WILLEY and the BLACK LIBERATION ARMY

- Mary Alice Willey was born in Anaheim, CA in 1949; she moved to San Francisco, CA in **September 1969** to attend college. She grew disillusioned with school, dropped out, and became involved in the Black Power movement. In high school she had been known as Carol**.**
- **21 August 1971**, she is thought to have smuggled a gun to George Jackson, a San Quentin prisoner, resulting in the killing of several prison guards and the death of Jackson during an escape attempt.
- **28 August 1971**, a woman fitting the description of Mary Alice (but who gave the name Carol George) entered a San Francisco police station to report a missing purse. After completing paperwork, she signaled to individuals outside the station, who entered and killed policemen in apparent retaliation for George Jackson's death.
- **11 September 1971**, the body of "Jane Doe" was discovered floating in a canal ditch in Stanislaus County.

Reconstructed travel history

San Francisco
(Hetch-Hetchy Reservoir)



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Anaheim, CA

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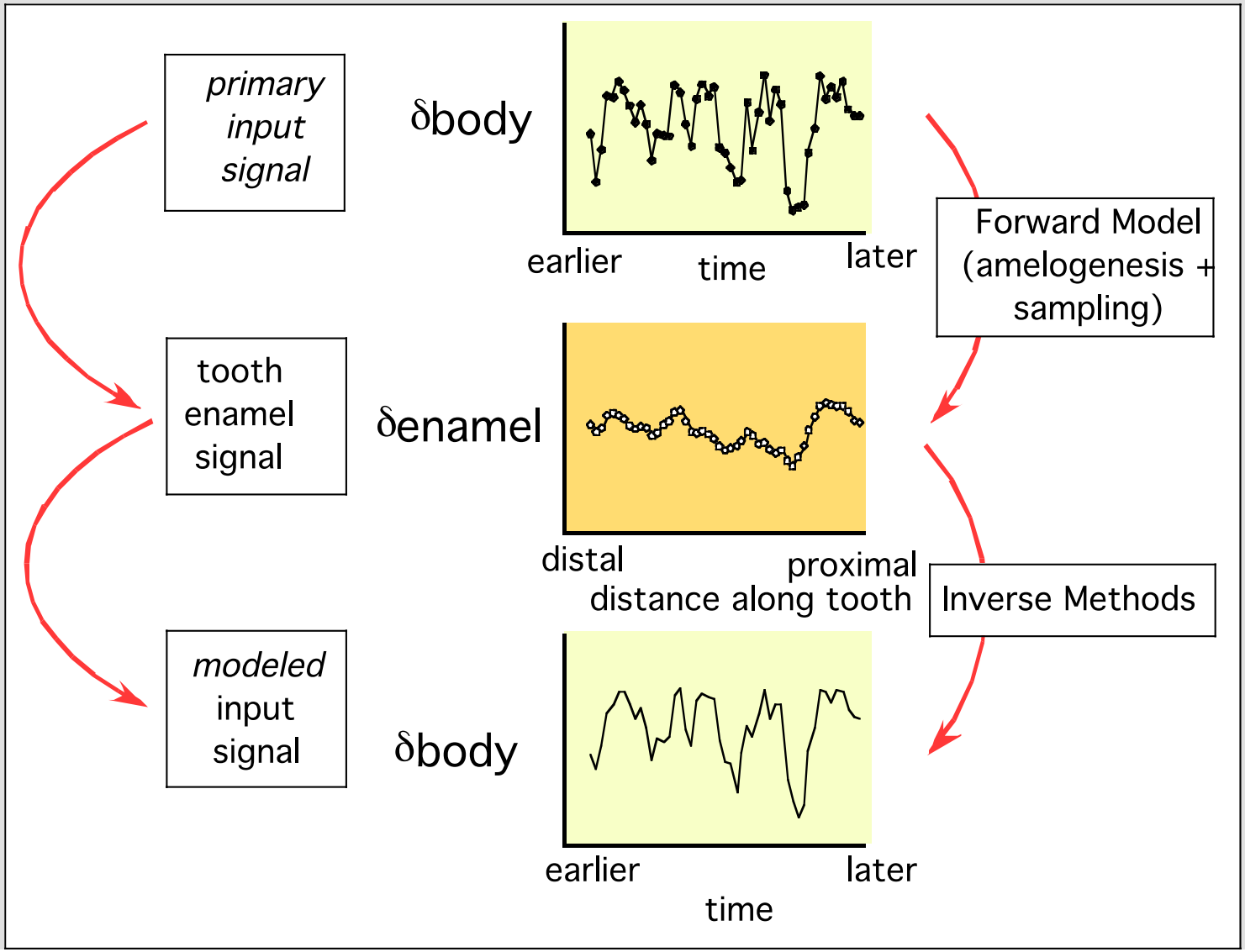
- ***Stable isotopes used for confirmation of DNA studies.***

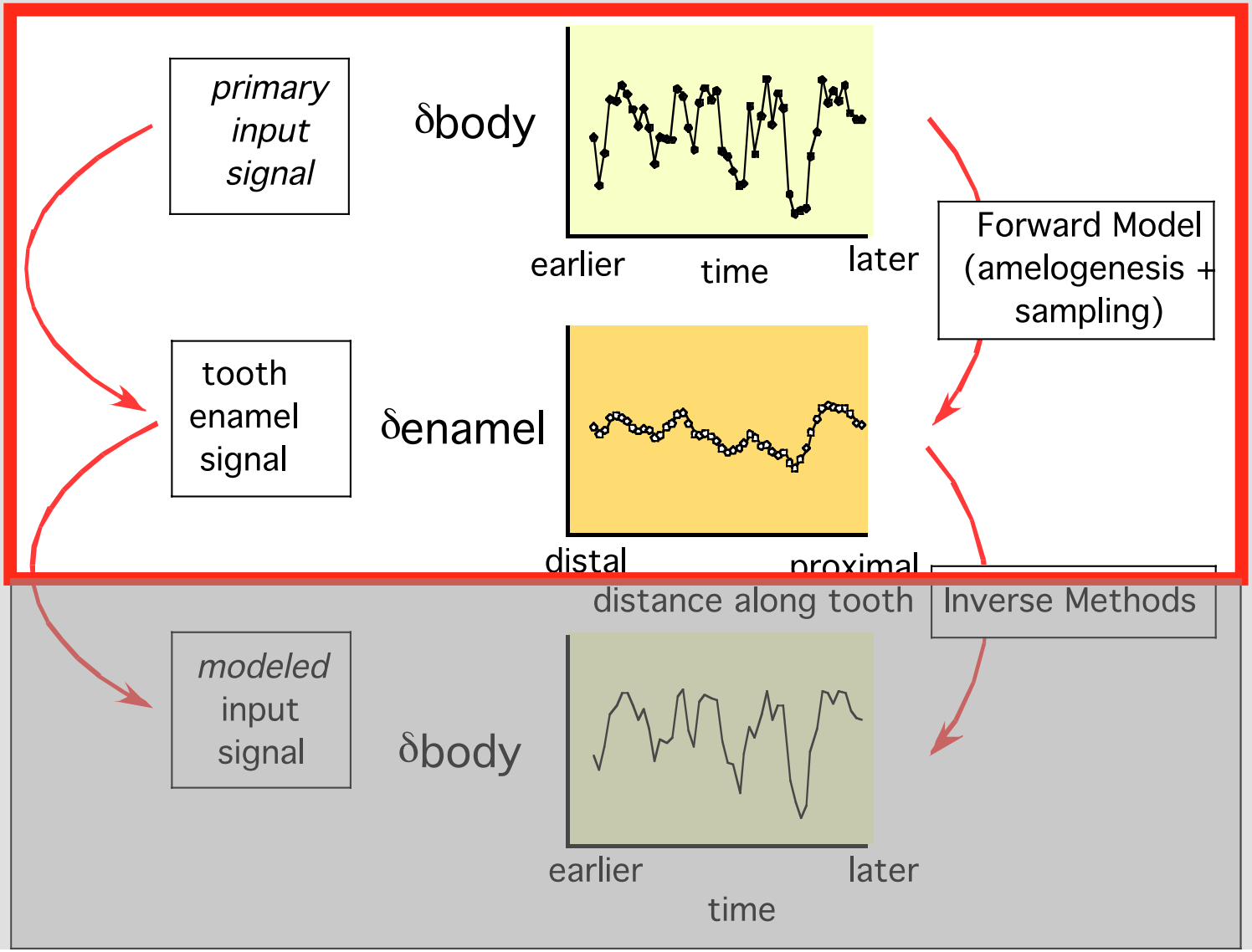
ID established in 2009.

Prospects for reconstruction of diets using tooth enamel

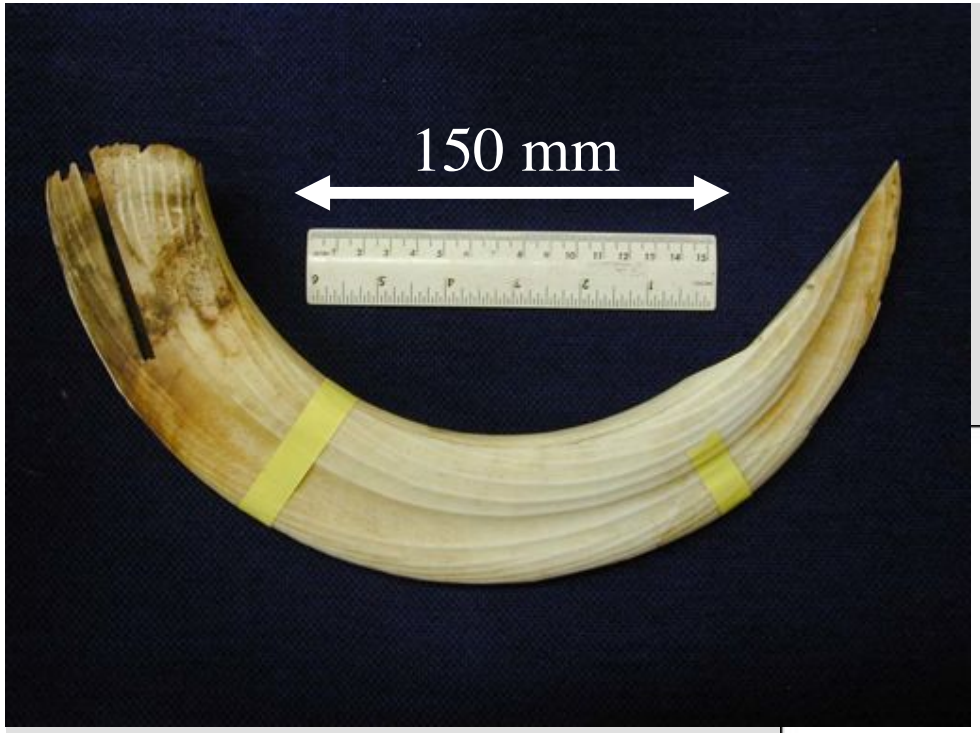
Real input vs. modeled output



Real input vs. modeled output



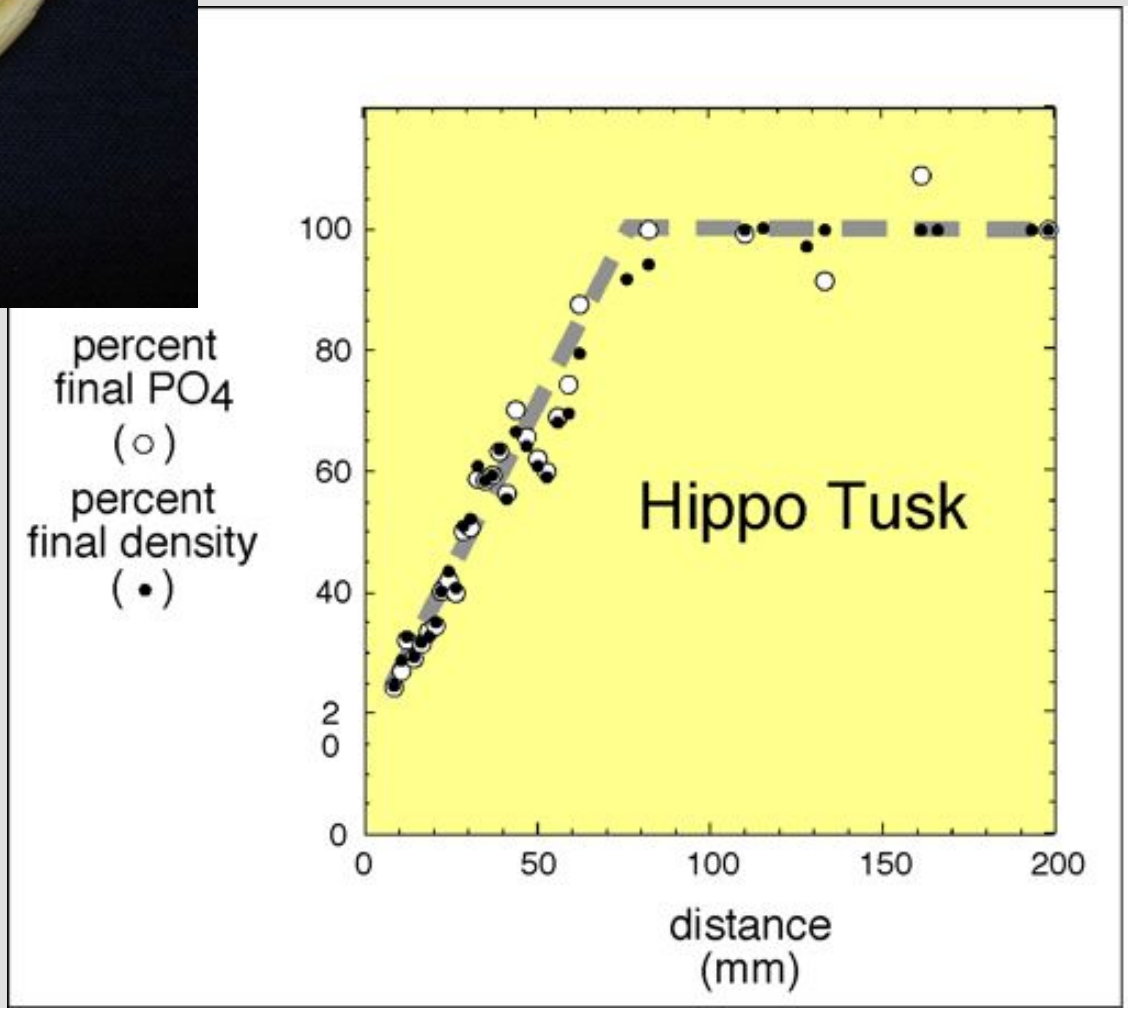
Enamel does not form all at once



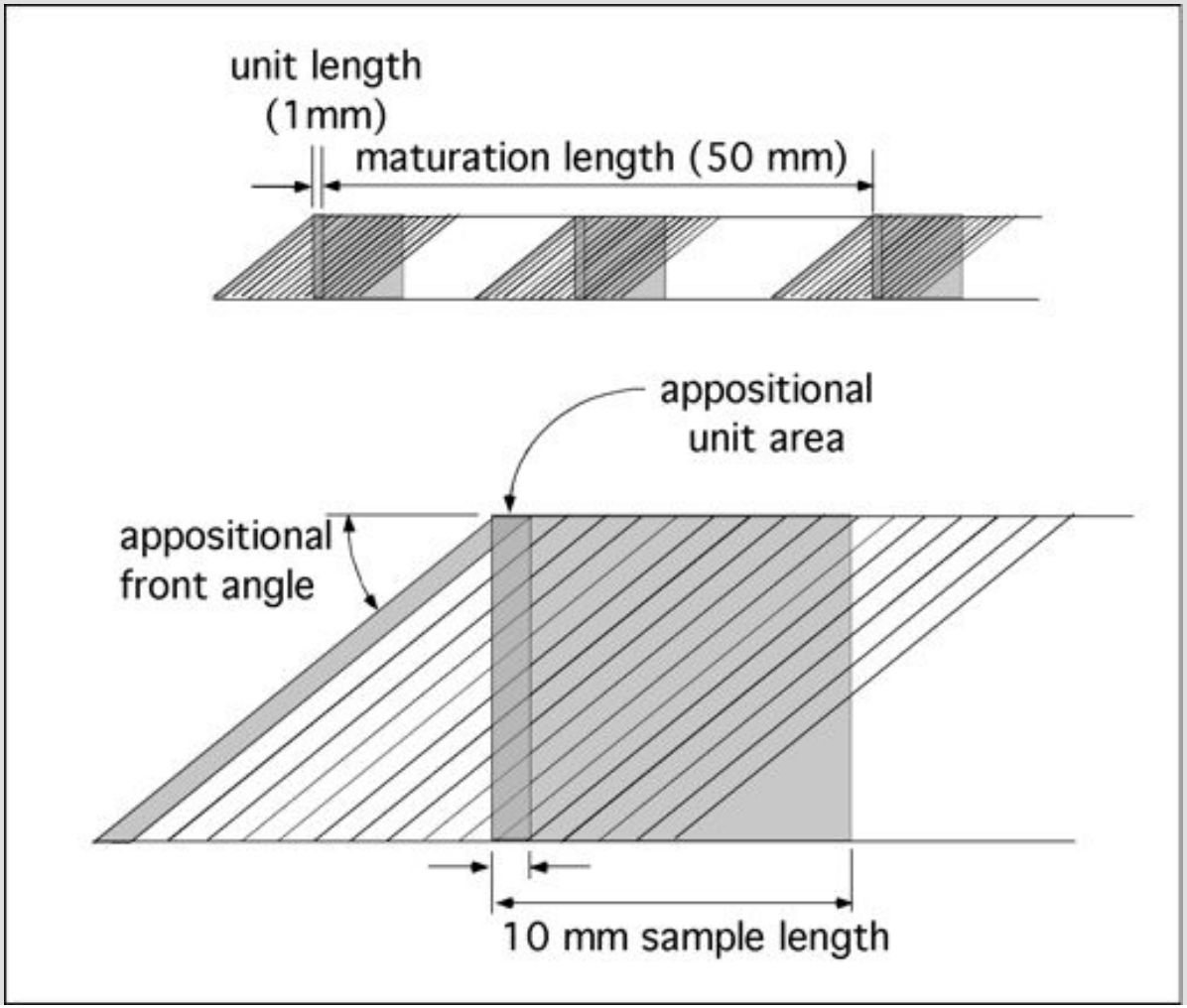
unit volume of enamel forms over time interval

Limit to sample resolution: can never get pure signal no matter what the sampling strategy

-Passey and Cerling, 2002



model for enamel maturation and sampling

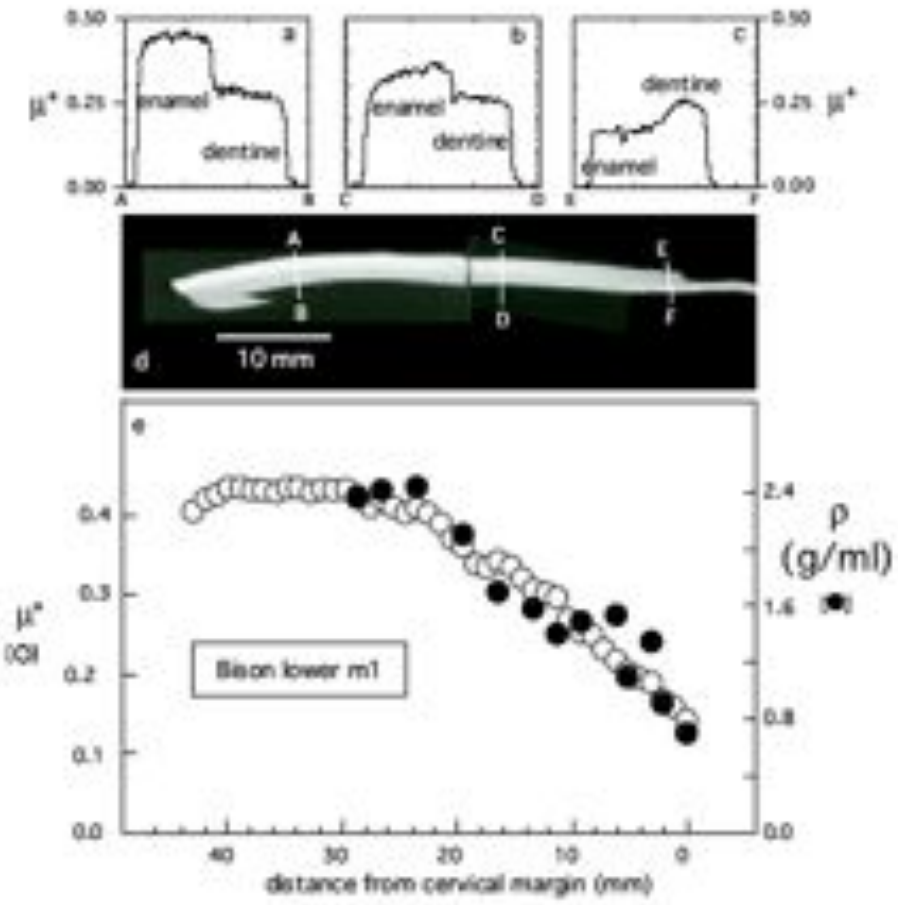


Maturation parameters: Micro-Computerized Tomography

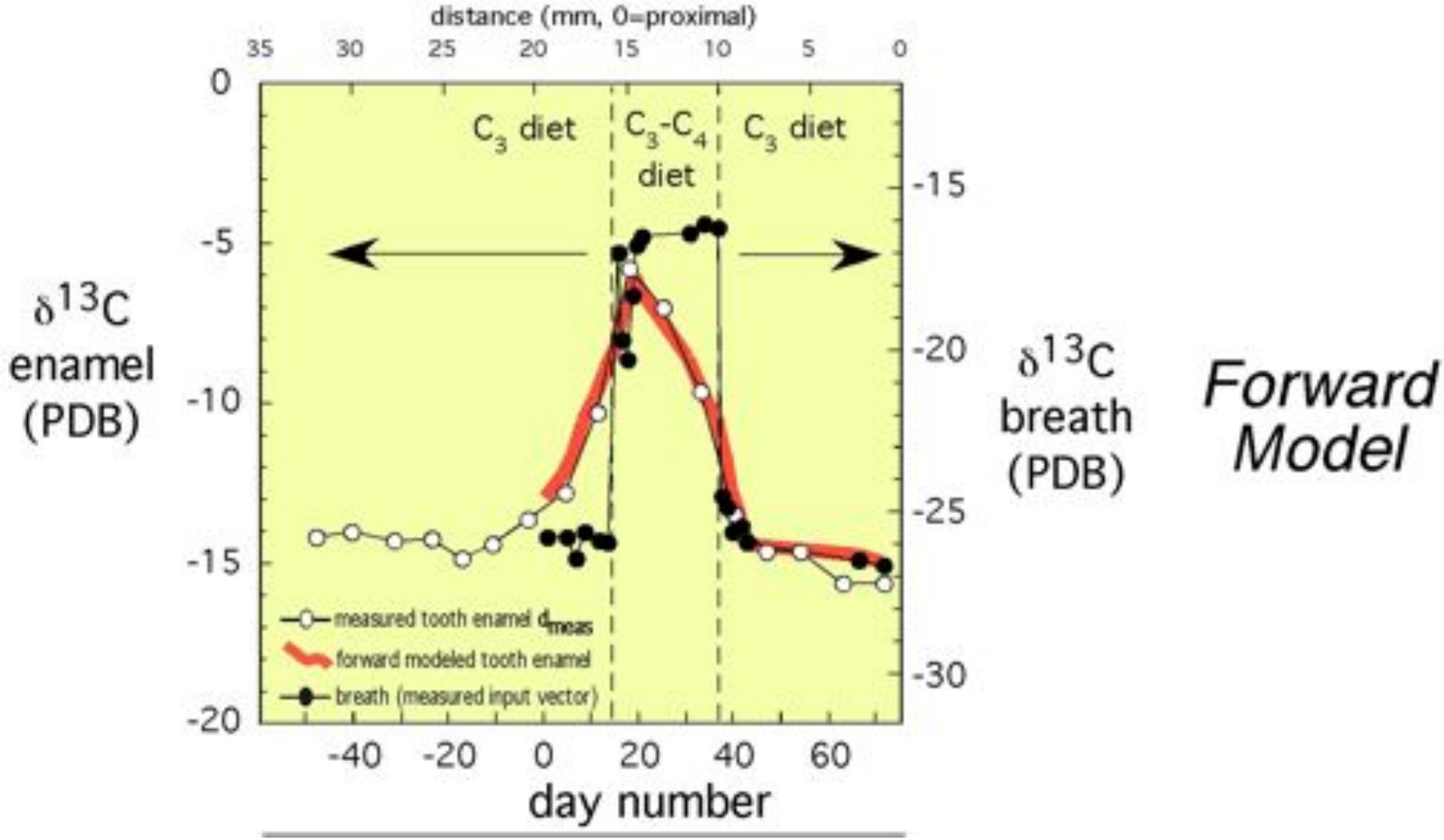
Micro-CT can be used to determine maturation parameters in developing tooth enamel

Corroborated by *in situ* density measurements

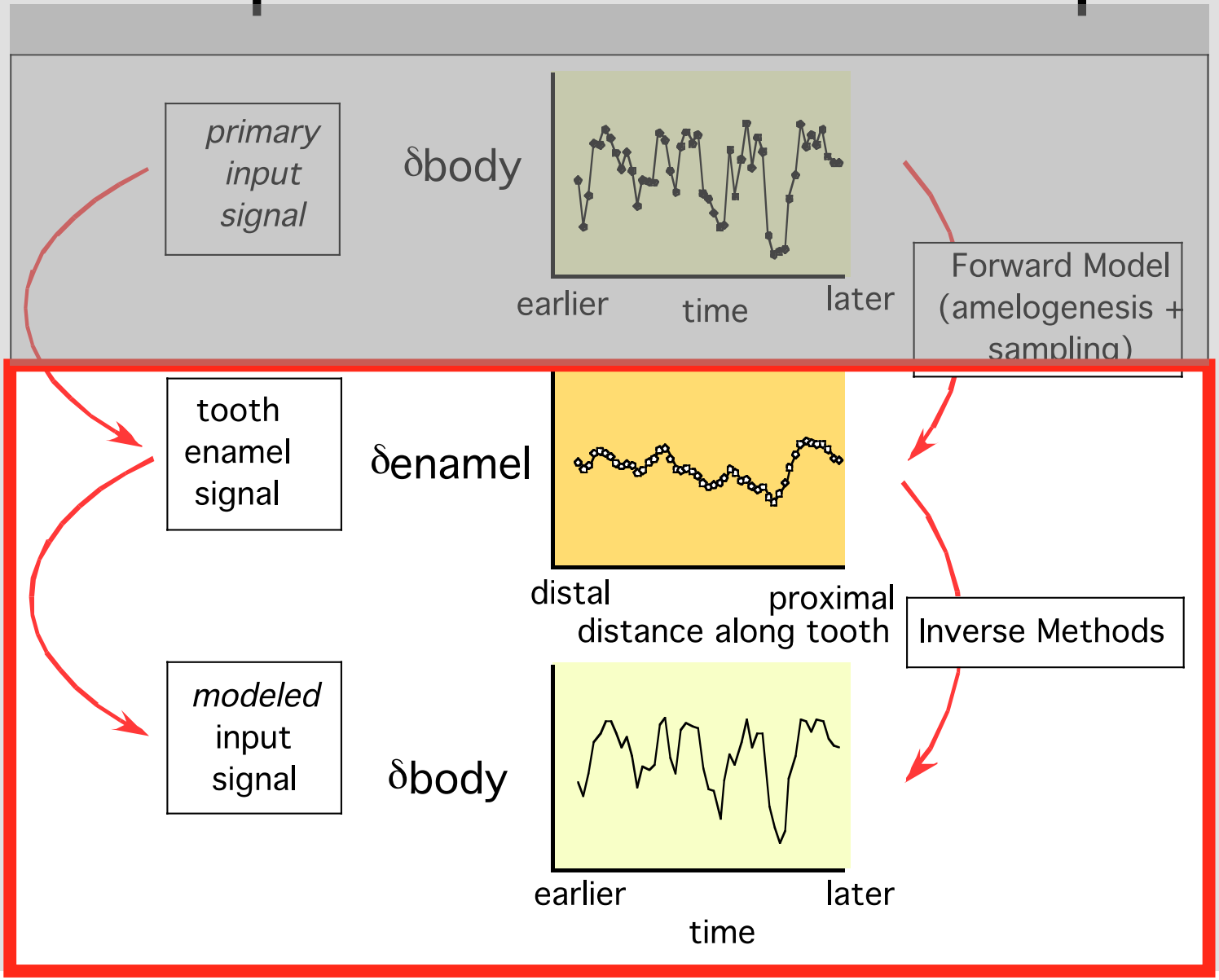
-Passey and Cerling, unpublished



Controlled diet change for rabbit. Forward model for teeth based on breath data and maturation parameters. Passey et al (2005).



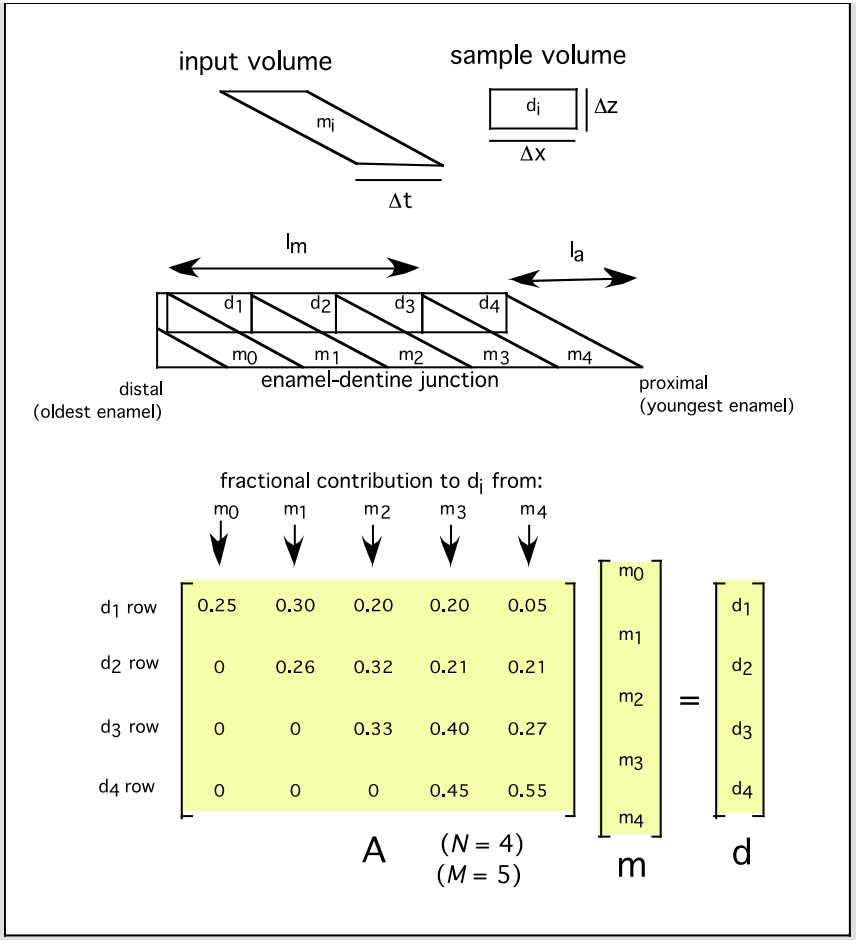
Real input vs. modeled output



Inversion solution: (Meinke's "moving camera")

Set up input as matrix:

$$\mathbf{Am = d}$$

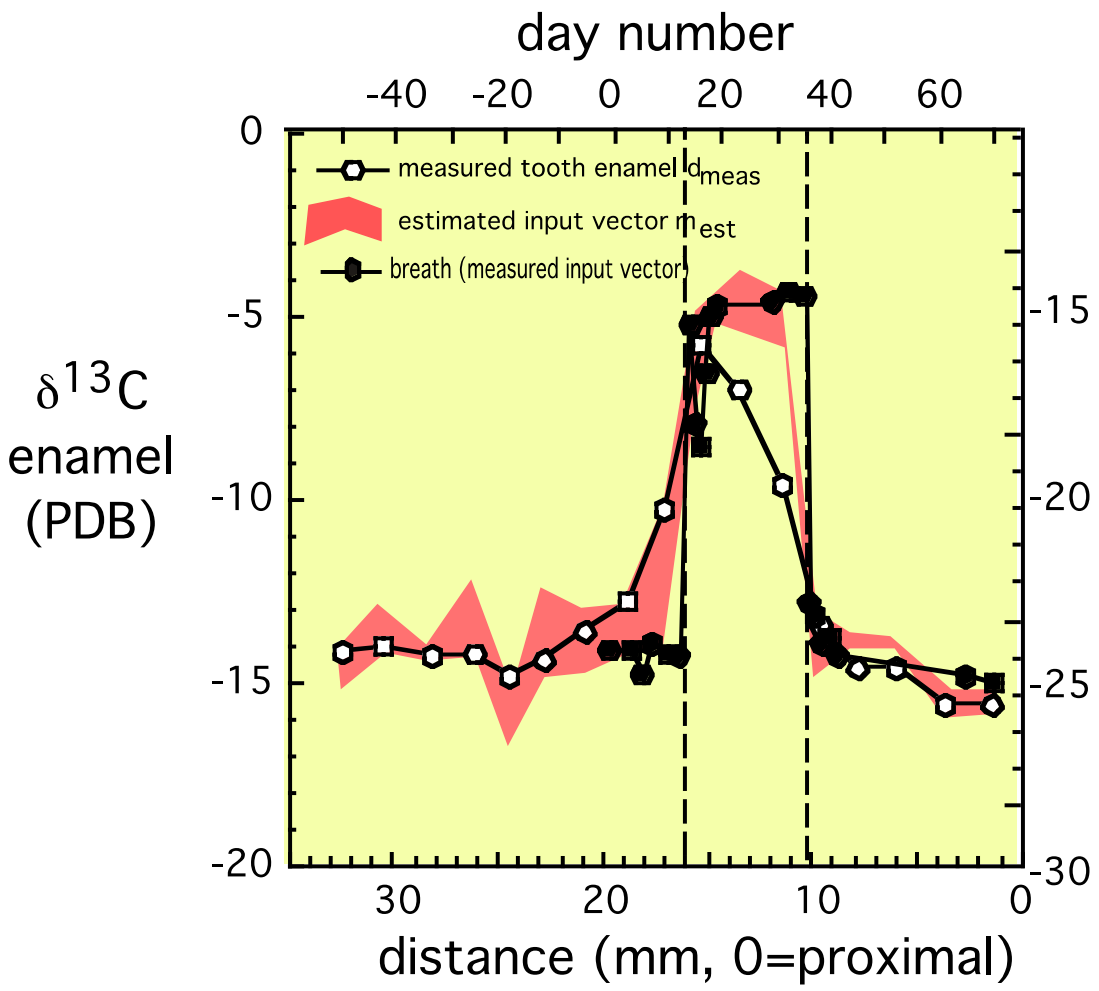


The inverse solution to solve for the input is:

$$\mathbf{m}_{est} = \langle \mathbf{m} \rangle + \mathbf{A}^T \left[\mathbf{A}\mathbf{A}^T + \varepsilon^2 \mathbf{I} \right]^{-1} \left[\mathbf{d} - \mathbf{A}\langle \mathbf{m} \rangle \right]$$

Passey et al., 2005

Inversion method recovers original input

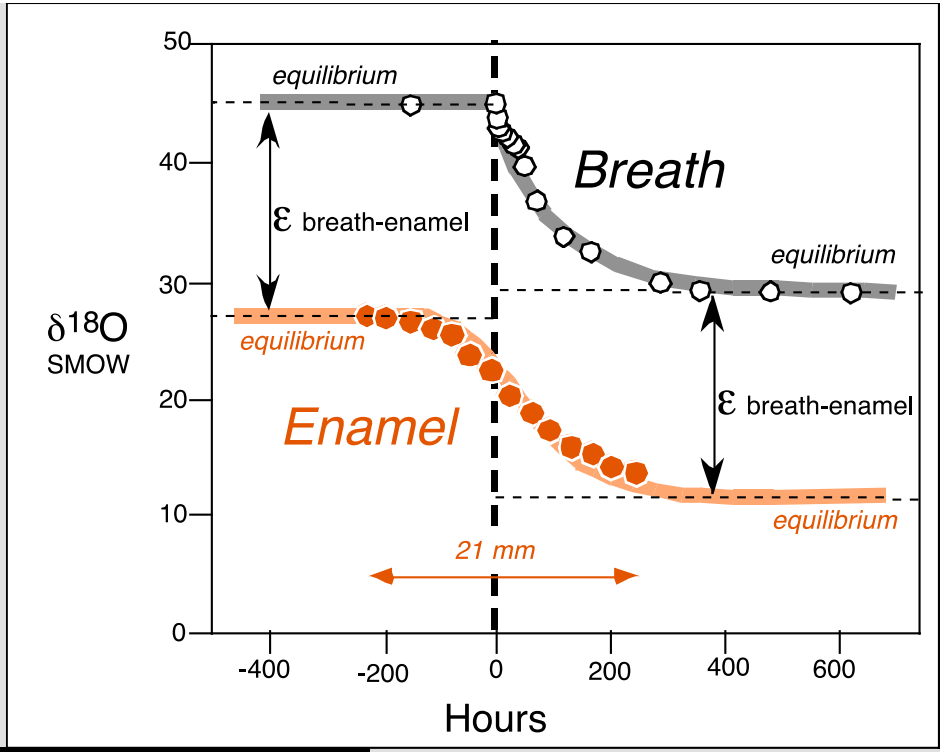


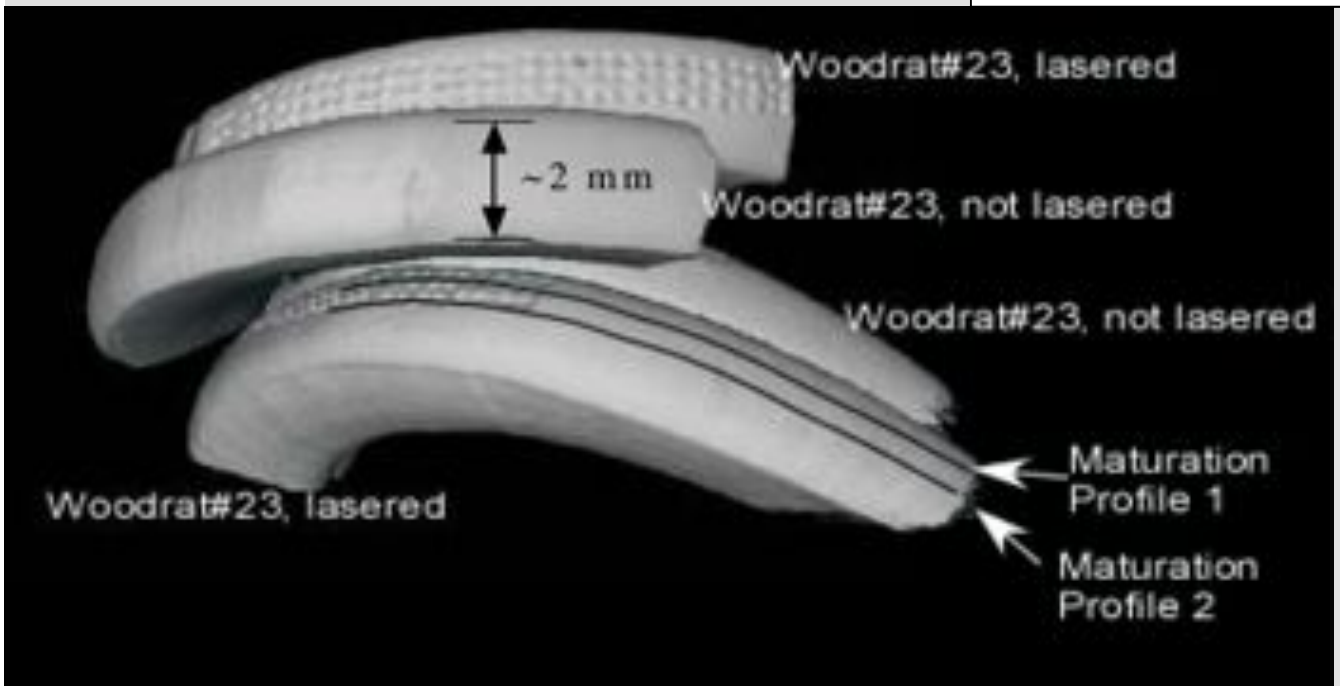
Inverse Model

Passey et al, 2005

Laser ablation: micro-sampling

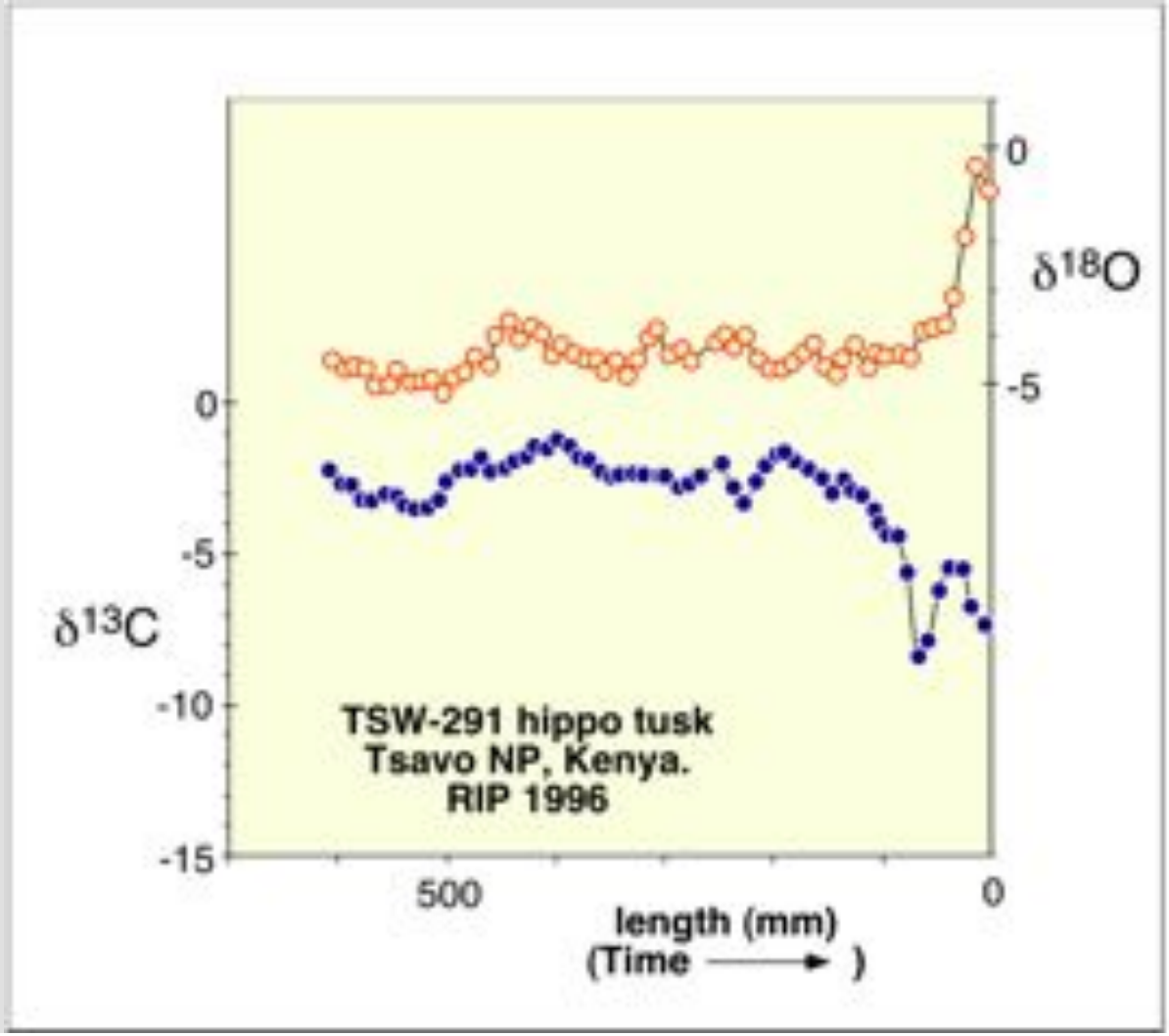
- Podlesak et al., 2007





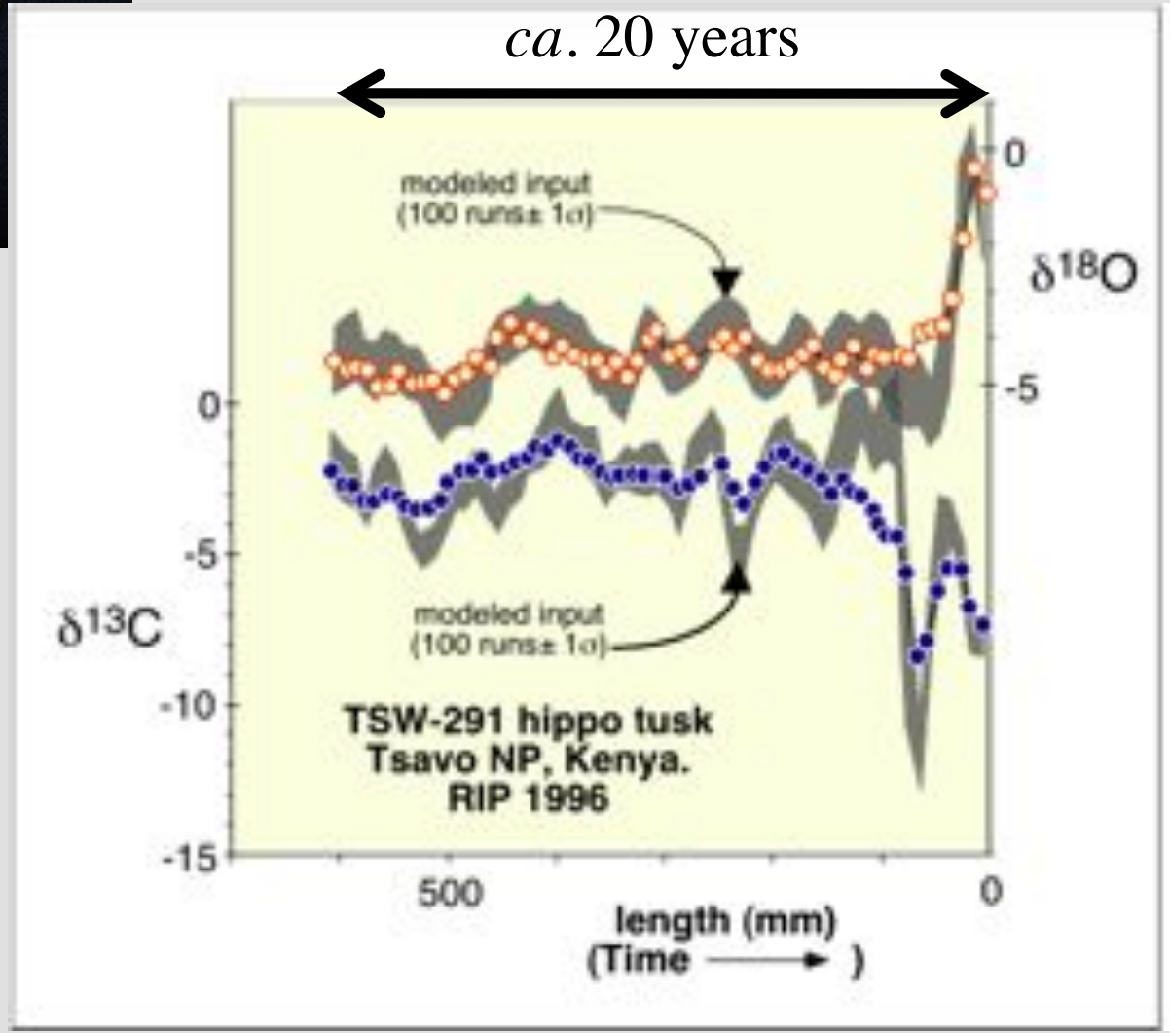
Hippo tusk: Tsavo NP, Kenya

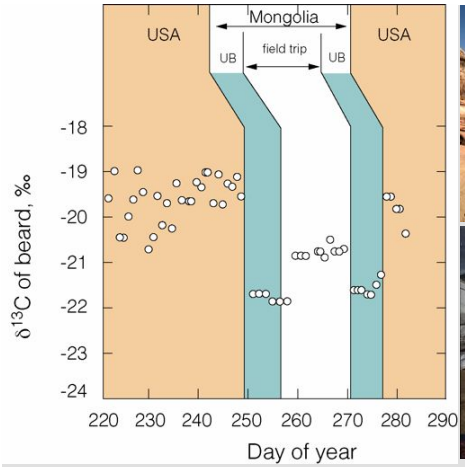
- 610 mm tusk
- Known facts: died during drought
- $\delta^{13}C$ shows gradual decline in diet quality, $\delta^{18}O$ shows gradual rise
- Reconstruction:
  - Severe diet stress
  - Severe water imbalance



Diet reconstruction

- 100 inversions: ±1σ
- lm = 45 to 65 mm
- la = 8 to 12 mm
- x ±1 mm; z±0.2mm
- $\delta^{13}C$: ±0.1‰.





You are what you eat (+ a few ‰):
you cannot escape your history

Modern: detailed history (to a single day)
- diet
- migration
- climate change
- land-use change